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Aggregate Resources Inventory of

The Echo Lake to Batchawana Bay Area

Ontario Geological Survey
Aggregate Resources Inventory
Paper 176

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By D.J. Rowell

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Abstract

This report includes an inventory and evaluation of the sand and gravel resources of 17 townships surrounding the City of Sault Ste. Marie. The project area covers approximately 170 000 ha to the north and east of the city. The report is based on a detailed field assessment undertaken in the summers of 1999 and 2000, and on previous studies in the area. The investigation was conducted to delineate and determine the quality and quantity of aggregate within the area to help ensure that sufficient aggregate resources are available for future use. The report is part of the Aggregate Resources Inventory Program for areas designated under the *Aggregate Resources Act* (ARA) 1989.

Ten Selected Sand and Gravel Resource Areas, occupying a total of 1523 ha, have been selected at the primary level. These resource areas, primarily glaciolacustrine beach and glaciofluvial outwash deposits, contain a possible aggregate resource of 161.7 million tonnes. Secondary and tertiary sand and gravel deposits add significantly to the overall granular resources in the study area, however, these deposits are distant from potential markets and some are isolated by a lack of road access.

Precambrian bedrock has the potential to supply large quantities of aggregate material. Bedrock is exposed throughout the study area and some of the bedrock lithologies (Nipissing diabase and Algoma granites) meet the specifications for high-end aggregate products. Thorough, site-specific testing of the bedrock should be completed before quarry development is undertaken.

Selected Resource Areas are not intended to be permanent, single land use units that must be incorporated in an official planning document. They represent areas in which a major resource is known to exist. Such resource areas may be reserved wholly or partially for extractive development and/or resource protection within the context of the official plan.

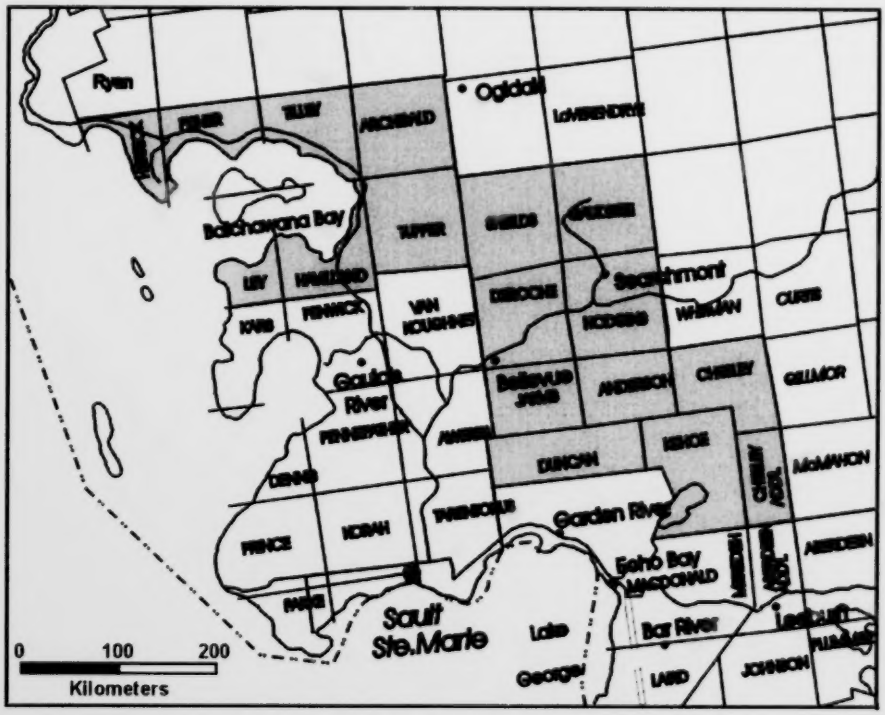

Figure 1. Key map showing the location of the study area.

Aggregate Resources Inventory of the Echo Lake to Batchawana Bay Area

By D. J. Rowell

Project Supervisor: C. L. Baker; fieldwork and report by D. J. Rowell; compilation and drafting by Staff of the Sedimentary Geoscience Section, Ontario Geological Survey. Assistance with review provided by the Resident Geologist, Ministry of Northern Development and Mines, Sault Ste. Marie, Ontario; the Ontario Ministry of Transportation, Thunder Bay, Ontario; and the Mineral Resources Staff, Sudbury District Office, Ministry of Natural Resources, Sudbury, Ontario.

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Introduction

Mineral aggregates, which include bedrock-derived crushed stone as well as naturally formed sand and gravel, constitute the major raw material in Ontario's road building and construction industries. Very large amounts of these materials are used each year throughout the Province. For example, in 1996, the total tonnage of mineral aggregates extracted in Ontario was 141 million tonnes, greater than that of any other metallic or nonmetallic commodity mined in the Province (Ontario Ministry of Natural Resources 1996).

Although mineral aggregate deposits are plentiful in Ontario, they are fixed-location, non-renewable resources that can be exploited only in those areas where they occur. Mineral aggregates are characterized by their high bulk and low unit value so that the economic value of a deposit is a function of its proximity to a market area as well as its quality and size. The potential for extractive development is often high in areas where land use competition is extreme. For these reasons the availability of adequate resources for future development is now being threatened in many areas, especially urban areas where demand is the greatest.

Comprehensive planning and resource management strategies are required to make the best use of available resources, especially in those areas experiencing rapid development. Unfortunately, in some cases, the best aggregate resources are found in or near areas of environmental sensitivity, resulting in the requirement to balance the need for the different natural resources. Therefore, planning strategies must be based on a sound knowledge of the total mineral aggregate resource base at both local and regional levels. The purpose of the Aggregate Resources Inventory Program is to provide the basic geological information required to include potential mineral aggregate resource areas in planning strategies. The reports should form the basis for discussion on those areas best suited for possible extraction. The aim is to assist decision-makers in protecting the public well-being by ensuring that adequate resources of mineral aggregate remain available for future use.

This report is a technical background document, based for the most part on geological information and interpretation. It has been designed as a component of the total planning process and should be used in conjunction with other planning considerations, to ensure the best use of an area's resources.

The report includes an assessment of sand and gravel resources as well as a discussion on the potential for bedrock-derived aggregate. The most recent information available has been used to prepare the report. As new information becomes available, revisions may be necessary.

Part I - Inventory Methods

FIELD AND OFFICE METHODS

The methods used to prepare the report involved the interpretation of published geological data such as bedrock and surficial geology maps and reports (see References), as well as field examination of possible resource areas. Field methods included the examination of natural and man-made exposures of granular material. Most observations were made at quarries and sand and gravel pits located from records held by the Ontario Ministry of Transportation (MTO), the Ontario Geological Survey (OGS), and by Regional, District and Area Offices of the Ontario Ministry of Natural Resources (MNR). Observations made at pit sites included estimates of the total face height and the proportion of gravel- and sand-sized materials in the deposit. Observations regarding the shape and lithology of the particles were also made. These characteristics are important in estimating the quality and quantity of the aggregate. In areas of limited exposure, subsurface materials may be assessed by hand augering and test pitting.

Deposits with potential for further extractive development or those where existing data are scarce were studied in greater detail. Representative sections in these deposits were evaluated by taking 11 to 45 kg samples from existing pit faces or from test pits. The samples were tested for grain size distribution, and in some cases the Los Angeles abrasion and impact test, absorption, magnesium sulphate soundness test and petrographic analyses are carried out. Analyses were performed in the laboratories of the Ontario Ministry of Transportation.

The field data were supplemented by pit information on file with the Geotechnical Section of the Ontario Ministry of Transportation. Data contained in these files includes field estimates of the depth, composition and "workability" of deposits, as well as laboratory analyses of the physical properties and suitability of the aggregate. Information concerning the development history of the pit and acceptable uses of the aggregate is also recorded. The locations of additional aggregate sources were obtained from records held by Regional, District and Area Offices of the Ontario Ministry of Natural Resources. In addition, reports on geological testing for type, quantity and quality of aggregates were also obtained from numerous aggregate licence applications on file with the MNR, and with specific individuals and companies. The cooperation of the above-named groups in the compilation of inventory data is gratefully acknowledged.

Aerial photographs at various scales are used to determine the continuity of deposits, especially in areas where information is limited. Water well records, held by the Ontario Ministry of the Environment, were used in some areas to corroborate deposit thickness estimates or to indicate the presence of buried granular material. These records were used in conjunction with other evidence.

Ontario Base Maps (OBMs), produced by the Ministry of Natural Resources at a scale of 1:20 000, were used as a compilation base for the field and office data. The information was then assembled for publication at a scale of 1:50 000.

RESOURCE TONNAGE CALCULATION TECHNIQUES

Sand and Gravel Resources

Once the interpretative boundaries of the aggregate units have been established, quantitative estimates of the possible resources available can be made. Generally, the volume of a deposit can be calculated if its areal extent and average thickness are known or can be estimated. The computation methods used are as follows. First, the area of the deposit, as outlined on the final base map, is calculated in hectares (ha). The thickness values used are an approximation of the deposit thickness, based on the face heights of pits developed in the deposit or on subsurface data such as test holes and water well records. Tonnage values can then be calculated by multiplying the volume of the deposit by 17 700 (the density factor). This factor is approximately the number of tonnes in a 1 m thick layer of sand and gravel, 1 ha in extent, assuming an average density of 1770 kg/m^3.

Tonnage = Area x Thickness x Density Factor

Tonnage calculated in this manner must be considered only as an estimate. Furthermore, such tonnages represent amounts that existed prior to any extraction of material (i.e., original tonnage) (Table 1, Column 4).

The Selected Sand and Gravel Resource Areas in Table 3 are calculated in the following way. Two successive subtractions are made from the total area. Column 3 accounts for the number of hectares unavailable because of the presence of permanent cultural features and their associated setback requirements. Column 4 accounts for those areas that have previously been extracted (e.g., wayside, unlicenced and abandoned pits are included in this category). The remaining figure is the area of the deposit currently available for extraction (Column 5). The available area is then multiplied by the estimated deposit thickness and the density factor (Column 5 x Column 6 x 17 700), to give an estimate of the sand and gravel tonnage (Column 7) possibly available for extractive development and/or resource protection. It should be noted however, that studies (Planning Initiatives Limited 1993) have shown that anywhere from 15 to 80% of the resources in an area may be further constrained or not accessible because of such things as environmental considerations (e.g., floodplains, environmentally sensitive areas), lack of landowner interest, resident opposition or other matters.

Resource estimates are calculated for deposits of primary significance. Resource estimates for deposits of secondary and tertiary significance are not calculated in Table 3, however, the aggregate potential of these deposits is discussed in the report.

Bedrock Resources

The method used to calculate resources of bedrock-derived aggregate is much the same as that described above. The areal extent of bedrock formations overlain by less than 15 m of unconsolidated overburden is determined from bedrock geology maps, drift thickness and bedrock topography maps, and from the interpretation of water well records (Table 4). The measured extent of such areas is then multiplied by the estimated quarriable thickness of the formation, based on stratigraphic analyses and on estimates of existing quarry faces in the unit. In some cases a standardized estimate of 18 m is used for thickness. Volume estimates are then multiplied by the density factor (the estimated weight in tonnes of a 1 m thick section of rock, 1 ha in extent).

Resources of limestone and dolostone are calculated using a density factor of 2649 kg/m^3, sandstone resources are calculated using a density estimate of 2344 kg/m^3, and shale resources are calculated with a factor of 2408 kg/m^3 (Telford, Geldart, Sheriff and Keys 1980).

Units and Definitions

The measurements and other primary data available for resource tonnage calculations are given in Metric units in the text and on the tables which accompany the report. Data are generally rounded off in accordance with the Ontario Metric Practices Guide (Ontario Interministerial Committee on National Standards and Specifications 1975).

The tonnage estimates made for sand and gravel deposits are termed possible resources (see Glossary, Appendix B) in accordance with terminology used by the Ontario Resource Classification Scheme (Robertson 1975, p.7) and the Association of Professional Engineers of Ontario (1976).

Part II - Data Presentation and Interpretation

Three maps accompany this report. Map 1A identifies sand and gravel resources in the Batchawana Bay area while Map 1B shows the distribution of granular material in the Echo Lake area. Map 2, entitled Bedrock Resources, illustrates the bedrock units throughout the study area. All maps are referenced in the contents of this report.

MAP 1: SAND AND GRAVEL RESOURCES

Map 1 shows the extent and quality of sand and gravel deposits within the study area and an evaluation of the aggregate resources. The map is derived from existing surficial geology maps of the area or from aerial photograph interpretation in areas where surficial mapping is incomplete.

The present level of extractive activity is also indicated on Map 1. Those areas which are licenced for extraction under the *Aggregate Resources Act* are shown by a solid outline and identified by a number which refers to the pit descriptions in Table 2. Each description notes the owner/operator and licenced hectarage of the pit, as well as the estimated face height and percentage gravel. A number of unlicenced pits (abandoned pits or pits operating on demand under authority of a wayside permit) are identified by a numbered dot on Map 1 and described in Table 2. Similarly, test hole locations appear on Map 1 as a point symbol and are described in Table 7.

Map 1 also presents a summary of available information related to the quality of aggregate contained in all the known aggregate deposits in the study area. Much of this information is contained in the symbols which are found on the map. The Deposit Symbol appears for each mapped deposit and summarizes important genetic and textural data. The Texture Symbol is a circular proportional diagram which displays the grain size distribution of the aggregate in areas where bulk samples were taken.

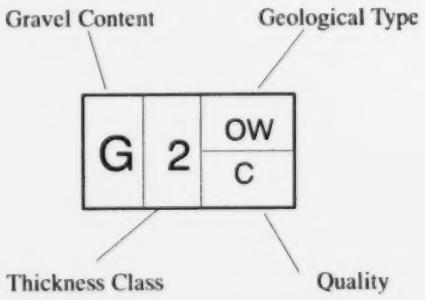
Deposit Symbol

The Deposit Symbol is similar to those used in soil mapping and land classification systems commonly in use in North America. The components of the symbol indicate the gravel content, thickness of material, origin (type) and quality limitations for every deposit shown on Map 1.

The "gravel content" and "thickness class" are basic criteria for distinguishing different deposits. The "gravel content" symbol is an upper case "S" or "G". The "S" indicates that the deposit is generally "sandy" and that gravel-sized aggregate (greater than 4.75 mm) makes up less than 35% of the whole deposit. "G" indicates that the deposit contains more than 35% gravel.

The "thickness class" indicates a depth range which is related to the potential resource tonnage for each deposit. Four thickness class divisions have been established as shown in the legend for Map 1.

Two smaller sets of letters, divided from each other by a horizontal line, follow the thickness class number. The upper series of letters identifies the geologic deposit type (the types are summarized with respect to their main geologic and extractive characteristics in Appendix C), and the lower series of letters identifies the main quality limitations that may be present in the deposit as discussed in the next section.



For example, the above symbol identifies an outwash deposit 3 to 6 m thick containing more than 35% gravel. Excess silt and clay may limit uses of the aggregate in the deposit.

Texture Symbol

The Texture Symbol provides a more detailed assessment of the grain size distribution of material sampled during field study. These symbols are derived from the information plotted on the aggregate grading curves found in the report. The relative amounts of gravel, sand, and silt and clay in the sampled material are shown graphically in the Texture Symbol by the subdivision of a circle into proportional segments. The following example shows a hypothetical sample consisting of 30% gravel, 60% sand and 10% silt and clay.

SELECTED SAND AND GRAVEL RESOURCE AREAS

All the Selected Sand and Gravel Resource Areas are first delineated by geological boundaries and then classified into 3 levels of significance: primary, secondary and tertiary. Each area of primary significance is given a deposit number and all such deposits are shown by red shading on Map 1.

Selected Sand and Gravel Resource Areas of primary significance are not permanent, single land use units. They represent areas in which a major resource is known to exist, and may be reserved wholly or partially for extractive development and/or resource protection. In many of the recently approved local and Regional/County Official Plans primary, and in some cases resources of secondary significance, are identified and protected.

Deposits of secondary significance are indicated by orange shading on Map 1. Such deposits are believed to contain significant amounts of sand and gravel. Although deposits of secondary significance are not considered to be the "best" resources in the report area, they may contain large quantities of sand and gravel and should be considered as part of the aggregate supply of the area.

Areas of tertiary significance are indicated by yellow shading. They are not considered to be important resource areas because of their low available resources, or because of possible difficulties in extraction. Such areas may be useful for local needs or extraction under a wayside permit but are unlikely to support large-scale development.

The process by which deposits are evaluated and selected involves the consideration of 2 sets of criteria. The main selection criteria are site specific, related to the characteristics of individual deposits. Factors such as deposit size, aggregate quality, and deposit location and setting are considered in the selection of those deposits best suited for extractive development. A second set of criteria involves the assessment of local aggregate resources in relation to the quality, quantity and distribution of resources in the region in which the report area is located. The intent of such a process of evaluation is to ensure the continuing availability of sufficient resources to meet possible future demands.

Site Specific Criteria

DEPOSIT SIZE

Ideally, selected deposits should contain available sand and gravel resources large enough to support a commercial pit operation using a stationary or portable processing plant. In practice, much smaller deposits may be of significant value depending on the overall resources in the rest of the project area. Generally, deposits in Class 1 (greater than 6 m thick), and containing more than 35% gravel are considered to be most favourable for commercial development. Thinner deposits may be valuable in areas with low total resources.

AGGREGATE QUALITY

The limitations of natural aggregates for various uses result from variations in the lithology of the particles comprising the deposit, and from variations in the size distribution of these particles.

Four indicators of the quality of aggregate may be included in the deposit symbols. They are: gravel content (G or S), fines (C), oversize (O) and lithology (L).

Three of the quality indicators deal with grain size distribution. The gravel content (G or S) indicates the suitability of aggregate for various uses. Deposits containing at least 35% gravel in addition to a minimum of 20% material greater than the 26.5 mm sie[illegible] are considered to be the most favourable extractive sites, since this content is the minimum from which crushed products can be economically produced.

Excess fines (high silt and clay content) may severely limit the potential use of a deposit. Fines content in excess of 10% may impede drainage in road subbase aggregate and render it more susceptible to the effects of frost action. In asphalt aggregate, excess fines hinder the bonding of particles. Deposits known to have a high fines content are indicated by a "C" in the quality portion of the Deposit Symbol.

Deposits containing more than 20% oversize material (greater than 10 cm in diameter) may also have use limitations. The oversize component is unacceptable for uncrushed road base, so it must be either crushed or removed during processing. Deposits known to have an appreciable oversize component are indicated by an "O" in the quality portion of the Deposit Symbol.

Another indicator of the quality of an aggregate is lithology. Just as the unique physical and chemical properties of bedrock types determine their value for use as crushed rock, so do various lithologies of particles in a sand and gravel deposit determine its suitability for various uses. The presence of objectionable lithologies such as chert, siltstone and shale, even in relatively small amounts, can result in a reduction in the quality of an aggregate, especially for high quality uses such as concrete and asphalt. Similarly, highly weathered, very porous and friable rock can restrict the quality of an aggregate. Deposits known to contain objectionable lithologies are indicated by an "L" in the quality component of the Deposit Symbol.

If the Deposit Symbol shows either "C", "O", or "L", or any combination of these indicators, the quality of the deposit is considered to be reduced for some aggregate uses. No attempt is made to quantify the degree of limitation imposed. Assessment of the 4 indicators is made from published data, from data contained in files of both the Ontario Ministry of Transportation (MTO) and the Sedimentary Geoscience Section of the Ontario Geological Survey and from field observations.

Quality data may also appear in Table 9, where the results of MTO quality tests are listed by test type and sample location. The types of tests conducted and the test specifications are explained in Appendixes B and E, respectively.

Analyses of unprocessed samples obtained from test holes, pits or sample sites are plotted on grain size distribution graphs. On the graphs are the Ontario Ministry of Transportation's gradation specification envelopes for aggregate products: Granular A and Granular B Type 1; Hot-Laid Asphaltic Sand Nos. 1, 2, 3, 4 and 8; and concrete

sand. By plotting the gradation curves with respect to the specification envelopes, it can be determined how well the unprocessed sampled material meets the criteria for each product. These graphs, called Aggregate Grading Curves, follow the tables in the report.

LOCATION AND SETTING

The location and setting of a resource area has a direct influence on its value for possible extraction. The evaluation of a deposit's setting is made on the basis of natural, environmental and man-made features which may limit or prohibit extractive development.

First, the physical context of the deposit is considered. Deposits with some physical constraint on extractive development, such as thick overburden or high water table, are less valuable resource areas because of the difficulties involved in resource recovery. Second, permanent man-made features, such as roads, railways, power lines and housing developments, which are built on a deposit, may prohibit its extraction. The constraining effect of legally required setbacks surrounding such features is included in the evaluation. A quantitative assessment of these constraints can be made by measurement of their areal extent directly from the topographic maps. The area rendered unavailable by these features is shown for each resource area in Table 3 (Column 3).

In addition to man-made and cultural features, certain natural features, such as provincially significant wetlands, may prove to be contraints. In this report such constraints have not been outlined and the reader is advised to consult with municipal planning staff and the local office of the MNR for information on these matters. Depending on the number and type of constraints, anywhere from 15 to 80% of the total resources in a municipality can become inaccessible when these or other specific local constraints are considered (Planning Initiatives Limited 1993).

The assessment of sand and gravel deposits with respect to local land use and to private land ownership is an important component of the general evaluation process. Since the approval under the Planning Act of the Mineral Aggregate Resource Policy Statement (MARPS) in the mid 1980s and the Comprehensive Set of Policy Statements, including MARPS, in March 1995, many of the more recently approved local and regional Official Plans now contain detailed policies regarding the location and operation of aggregate extraction activity and should be consulted at an early date in regard to considering the establishment of an aggregate extraction operation. These aspects of the evaluation process are not considered further in this report, but readers are encouraged to discuss them with personnel of the pertinent office of MNR, and regional and local planning officials.

Regional Considerations

In selecting sufficient areas for resource development, it is important to assess both the local and the regional resource base, and to forecast future production and demand patterns.

Some appreciation of future aggregate requirements in an area may be gained by assessing its present production levels and by forecasting future production trends. Such an approach is based on the assumptions that production levels in an area closely reflect the demand, and that the present production "market share" of an area will remain roughly at the same level. In most cases, however, the market demand for aggregate products, especially in urban areas, is greater than the amount of production found within the local market area. Consequently, conflicts often arise between the increasing demand for aggregates in such areas and the frequent pressures to restrict aggregate operations, especially in the near urban areas.

The aggregate resources in the region surrounding a project area should be assessed in order to properly evaluate specific resource areas and to adopt optimum resource management plans. For example, an area that has large resources in comparison to its surrounding region constitutes a regionally significant resource area. Areas with high resources in proximity to large demand centres, such as metropolitan areas, are special cases.

Although an appreciation of the regional context is required to develop comprehensive resource management techniques, such detailed evaluation is beyond the scope of this report. The selection of resource areas made in this study is based primarily on geological data or on considerations outlined in preceding sections.

MAP 2: BEDROCK MAP

Precambrian bedrock may exhibit wide variations with respect to aggregate quality over relatively short distances. Precambrian rocks are usually hard and relatively homogeneous, but brittle varieties can occur and should be avoided in aggregate use. Massive, coarse-grained felsic plutonic and gneissic rocks with high mica, feldspar and quartz content may have bonding problems. The smooth cleavage and fracture surfaces of the minerals hinder the adhesion of asphalt and Portland cement concrete mixes.

Huronian Supergroup rocks were subject to folding and metamorphism. Because of extensive mineral and structural alterations, certain lithologies may be alkali-silica reactive. For example, greywackes and argillites may contain coarse-grained quartz with a deformed crystal lattice. This type of quartz is an alkali-silica reactive mineral, meaning that the quartz is likely to react with alkalies from the cement paste and may cause expansion and cracking of the concrete (Rogers 1985). This characteristic may restrict the use of these rocks to road construction applications only. Certain lithologies within the Huronian sequence have been found excessively hard and could not be economically quarried elsewhere.

For these reasons, the aggregate potential of the Precambrian rock units that underlie the study area have not been accessed.

Having stated these limitations, there are Precambrian rock units in the area that have the potential to make excellent aggregate products. Extensive, site-specific testing is required to define these units and production may involve processing techniques.

Part III - Assessment of Aggregate Resources from Echo Lake to Batchawana Bay Area

LOCATION AND POPULATION

This report includes an inventory and an aggregate resource assessment of 17 townships surrounding the City of Sault Ste. Marie. The project area covers approximately 170 000 ha to the north and east of the city (Figure 1). In January 1999, these townships were designated under the *Aggregate Resources Act* (1989). The study area is covered by parts of the Ile Parisienne (41K/10), Pancake Bay (41K/15), Searchmont (41K/16), Sault Ste. Marie (41J/9), Echo Lake (41J/12) and Ranger Lake (41J/13) 1:50 000 scale map sheets of the National Topographic System (NTS).

Highway 17, following the north shore of Lake Huron and the eastern shoreline of Lake Superior, provides access throughout the map area. Highways 563, 556, 532 and forest access roads link the Highway 17 corridor with the interior of the study area. A line of the Algoma Central Railway traverses across the northwest corner of the Echo Lake map sheet (Map 1B).

The region is an area of recreational activity with cottages located along Pancake, Batchawana and Havilland bays. Provincial parks are located along the shores of Pancake and Batchawana bays while skiing and other recreational activities are available at Searchmont.

SURFICIAL GEOLOGY AND PHYSIOGRAPHY

During the Pleistocene Epoch all of Ontario was covered by a succession of ice sheets separated by interglacial periods. The last glacial advance, referred to as the Late or Classical Wisconsinan Stage, began approximately 23 000 years before present (Barnett 1992). Bedrock striations in the study area indicate that glacial ice flow was predominantly in a south-southwesterly direction on the uplands. The mean average orientation of the striae in the region is 200° (Boisonneau 1965, 1968). South trending eskers, which are common to the region north and east of the project area, attest to the general direction of ice movement (Boissoneau 1965, 1968).

A thin discontinuous cover of till was deposited throughout the study area by glacial ice. There would appear to be 2 till facies in the project area since there is no evidence to suggest any age difference between the till types. The Precambrian uplands comprise a rock-drift complex dominated by rock outcrops and shallow subcrops, however, a discontinuous till cover is present throughout. The till in this upland area occurs as a grey, stony to bouldery, sandy to sandy silt till. On weathering, it loses cohesion and consists of a pale brown to light brown bouldery fine sand till (Cowan and Broster 1988). The thickness of the till is highly variable ranging from 1 to 2 m adjacent to outcrops and up to 10 m on sideslopes.

The second till facies is a reddish brown, stony, sandy silt till derived from and generally overlying the Jacobsville Formation (Map 2). This till takes its color from the sandstone. Laboratory testing indicates that the textural composition of the till is similar to that of the sandstone when the rock is broken down through autogenous grinding (Cowan and Broster 1988).

Ice-contact deposits in the area are rare. Isolated deposits outside the study area have been mapped near Wabos, Karalash Corners and Garden River.

During deglaciation, glacial meltwater deposited outwash sand and gravel in spillway channels that are presently occupied by large rivers. In a few places, the spillways broaden into flat outwash plains. The thickness of the outwash deposits is variable and they commonly consist of sand with some gravel. Underlying materials vary from varved silt and clay to glacial till and bedrock. Stratigraphic sequences are evident along the Goulais, Garden and Chippewa rivers.

About 10 500 to 11 000 years ago, following deglaciation, glacio-isostatic depression of the land allowed glacial Lake Algonquin to inundate the area. At this time, Lake Algonquin occupied the Huron, Michigan and eastern Superior basins. The Main Algonquin level in the Sault Ste. Marie area to the south is marked by the large barrier-bar complex fronting the Gros Cap Highland with an upper surface at about 309 msl (Cowan and Broster 1988).

Glaciolacustrine nearshore and deltaic sand can be up to 90 m thick and consist primarily of laminated to cross-laminated fine and medium sand with minor gravel. Considerable longshore drift movement occurred to redistribute materials along the Lake Algonquin shoreline. The glaciolacustrine beach gravels are very well-sorted, well-rounded and often up to 6 m thick. Most gravel occurs in the upper few metres as a result of reworking of sediment and the deposition of sandy gravel on the beach face during lowering lake levels (Cowan and Broster 1988).

In the deeper waters of Lake Algonquin, massive and/or varved silt and clay were deposited. As with the tills, some of the clays are pink to reddish brown (Cowan and Broster 1988). Glaciolacustrine sediments, consisting largely of silty fine sand, were deposited in the shallower areas of the glacial lake. In the study area most of these deposits occur along the shoreline of Batchawana Bay. These glaciolacustrine sands are generally too fine for most aggregate uses.

Isostatic rebound and the opening of lower outlets south of North Bay about 10 000 years ago led to a drop in water level from glacial Lake Algonquin and the development of a series of shoreline and nearshore features representing short-lived water levels. About 9 000 years ago an outlet to the east of North Bay allowed the water in the Hu-

ron basin to drain to a very low level (Lake Stanley level). Evidence of this low level consists of tree stumps and organic accumulations now covered by the water of Lake Huron (Cowan, McAuley and Bennett 1998). Uplift of this outlet caused the water levels to rise again, culminating in the development of a very strong glacial Lake Nipissing shoreline at about 4500 years ago (Cowan 1976). The rising water was recorded in the Sault Ste. Marie area by lacustrine and alluvial sediments in the Goulais, Root and Garden River valleys. The Nipissing shoreline at Sault Ste. Marie is represented by an erosional bluff at 198 m above sea level, which is eroded primarily into glaciolacustrine varved and laminated silts and clays.

Since the end of the Pleistocene, alluvium has accumulated along the flood plains of many river and stream valleys. The alluvial deposits consist mainly of silty sand and gravel and are usually less than 2 m thick.

Organic deposits have accumulated in many poorly drained depressions in the upland areas, in bedrock basins and in other locations with a high water table. Organic deposits are usually less than 2 m thick and are limited in areal extent.

The most prominent physiographic feature of the study area is the rock knob terrain that dominates the map area. Dissection of the bedrock along northwest and northeast trending faults and joints (Map 2) has developed strong relief, with local elevation differences that can exceed 100 m. Several peaks rise to more than 300 m above Lake Superior. The generally rugged topography has resulted in common bedrock exposures. The drainage pattern is largely controlled by bedrock structural features.

SELECTED SAND AND GRAVEL RESOURCE AREAS

Maps 1A and 1B indicate deposits that contain granular materials. These deposits occupy a total of 26 499 ha and contain an original resource tonnage of 2443.3 million tonnes (Table 1). **These figures represent a comprehensive inventory of all granular materials in the map area, although much of the material included in the estimate has no potential for use in aggregate products.**

Glaciofluvial outwash deposits are potential sources of aggregate within the map area. They are usually located within the northeast and northwest trending bedrock faults and joints which control the drainage pattern.

Glaciolacustrine beach deposits lie parallel to Lake Superior, a short distance inland from the present shoreline. Many of these deposits have a high sand content, but some good quality gravel does exist. Numerous pits have been developed in these beach deposits.

Nearshore and shallow water sand is widespread in the lowland areas. These deposits range in thickness from less than 1 m to more than 15 m. Glaciolacustrine lake plain deposits are found in the lowland areas adjacent to Lake Superior (less than 300 msl in elevation), along the lower Goulais River Valley and northwest of Goulais and Batchawana Bay.

Till is usually not well-suited for aggregate use as it often contains excess fines and abundant cobbles and boulders. However, it may be a suitable source of fill in some locations.

Many of the deposits listed at the secondary level of significance would be primary deposits if they were located closer to market. The large outwash deposit located in the northeast corner of Archibald Township is an excellent example. A representative sample taken from Pit No. 34 had 70.1% coarse material, with 28.4% sand and 1.5% fines (Figures 3A and 3B). The Petrographic Number for granular and 16 mm crushed was 100.3 and 102.5 for HL and concrete. The Micro Deval for coarse aggregate was 5.6% and 9.8% for fine aggregate (Table 9). The material should be suitable for the production of Granular A, B, SSM, HL and concrete. The deposit's suitability for development is limited due to its remoteness (15 km to Highway 17) and poor access. Also, the bridge located in the northeast corner of Archibald Township would need to be upgraded to handle the heavy vehicular loads.

Sand and Gravel Extractive Activity

One hundred and sixty-five operating and abandoned sand and gravel pits were identified in the study area (Table 2). At the time of writing, 5 licenced pits occupied 250.6 ha and were licenced for an annual production of 100 000 tonnes. This represents the maximum licenced aggregate production, however, the total aggregate production in the area would likely be significantly less. Records of production have not been kept in the past because the area was not designated under the ARA until January 1999. Now that the area has been designated, it is anticipated that production figures will be available.

Selected Sand and Gravel Resource Area 1 (Map 1A)

Selected Sand and Gravel Resource Area 1 is a large beach deposit located just south of Highway 17 in north-central Herrick Township. A forest access road links this selected resource area to the Highway 17 corridor and the Ontario Ministry of Transportation (MTO) has already established a pit (Pit No. 2) within this deposit. Good quality aggregate material is shallower in the south end of the selected resource area and the presence of red clay under the aggregate material was observed.

Previous MTO test results from Pit No. 2 indicate a coarse aggregate content of 48.5%, with 50.5% sand and 0.7% fines. The Petrographic Number (PN) for granular and 16 mm crushed was 101.0 and 127.6 for HL and concrete (Table 9). The aggregate within this deposit should be acceptable for the production of Granular A, B, Select Subbase Material (SSM) and HL4 (CA). Selective extraction and blending should allow the material from this selected resource area to meet HL4 (FA) specification.

Selected Sand and Gravel Resource Area 1 occupies a total of 134.5 ha with 124.4 ha available for resource development. Possible aggregate resources, based on an average deposit thickness of 6 m, would be 13.2 million tonnes (Table 3).

A large beach deposit just south of selected resource area 1 has been selected at the secondary level of significance. Testing from Pit No. 6 indicates 56.4% coarse material, 41.5% sand and 2.1% fines (Figures 2A and 2B). The PN is 100.5 for granular and 16 mm crushed and 113.7 for HL and concrete. The Micro Deval was 7.5% for coarse aggregate and 9.8% for fine (Table 9). This area has been listed as secondary because it is a shallow deposit. Bedrock was observed within 1 m of the surface at Pit Nos. 3 and 7 and the water table was noted in Pit No. 6 within 2 m of the surface. Good quality material is available from this area, but the thickness of this deposit may restrict pit development.

Selected Sand and Gravel Resource Area 2

The second selected resource area of primary significance is located just south of Selected Sand and Gravel Resource Area 1 and the large secondary beach deposit as noted above. This area can be accessed by a forest access road from the north or Highway 563 to the east.

Test results for Pit No. 8 indicate 83.6% coarse material and 16.4% sand (Figures 2A and 2B). Petrographic Numbers for granular and 16 mm crushed are 100.0 and 112.0 for HL and concrete (Table 9). Large clasts range in size from 12 to 18 cm. The material in Pit No. 13 did not appear to be as coarse as the material from Pit No. 8, but once again the material did appear to be of good quality. This aggregate should be able to meet specifications for Granular A, B, SSM, HL and concrete.

Selected Sand and Gravel Resource Area 2 occupies a total of 520.7 ha which is reduced to 512.6 ha due to cultural constraints and previous extraction activity. The possible aggregate resources available from this selected resource area would be approximately 54.4 million tonnes based on an average deposit thickness of 6 m (Table 3).

Selected Sand and Gravel Resource Area 3

Selected Sand and Gravel Resource Area 3 is another segment of this large beach deposit that occurs in Herrick and Fisher townships. Access to Highway 17 is provided by a well-maintained forest access road.

Pit Nos. 9 and 12 have been developed within this deposit. Previous MTO results from Pit No. 9 indicate a coarse aggregate content of 71.6%, with 23.4% sand and 4.6% fines. Petrographic Numbers vary from 102.4 for granular and 16 mm crushed to 125.7 for HL and concrete (Table 9). The aggregate material should be acceptable for the production of Granular A, B, SSM and HL4 (CA) with selection and blending.

Selected resource area 3 occupies 177.3 ha when cultural constraints and previous extraction activity have been considered. Assuming a deposit thickness of 6 m, 18.8 million tonnes of possible aggregate resource should be available (Table 3).

Selected Sand and Gravel Resource Area 4

Two deposits make up Selected Sand and Gravel Resource Area 4. The northern deposit is a small glaciolacustrine beach deposit that is located within 5 km of Highway 17. The southern segment is a beach deposit located immediately north of Highway 17. Both deposits are located near or along the Fisher – Tilley township boundary and both can be accessed by the same forest access road.

The MTO currently have a pit (Pit No. 23) located within the southern beach deposit. Previous MTO testing indicates a coarse aggregate content of 11.8%, with 87.9% sand and 0.3% fines. MTO have this pit listed as mainly a source of sand, acceptable for the production of Granular B and SSM. The proximity to Highway 17 makes this deposit quite valuable.

Pit No. 19 has been developed in the northern beach deposit. Gradation tests indicate a coarse aggregate content of 63.5%, with 35.8% sand and 0.5% fines. The large clasts range in size from 15 to 22 cm. This aggregate material should be acceptable for the production of Granular A, B, SSM and HL4 (CA).

Selected resource area 4 occupies 44.8 ha with 35.1 ha available for possible resource extraction. Assuming an average deposit thickness of 6 m, possible aggregate resources of 3.7 million tonnes should be available (Table 3). Coarser aggregate material from the northern beach deposit could be blended with material from the southern deposit to produce even higher specification products.

Selected Sand and Gravel Resource Area 5

An outwash deposit located in the northeast corner of Tilley Township has been designated as Selected Sand and Gravel Resource Area 5. This deposit is located about 12 to 15 km from the Highway 17 corridor but the forest access road connecting this area to the corridor is well-maintained. Heavy forestry vehicles have travelled this road extensively so aggregate vehicles should be able to do the same.

Test results for Pit No. 27 indicate 53.7% coarse material, 44.1% sand and only 2.2% fines. The large clast size ranges from 12 to 18 cm. The aggregate material from this area should be able to meet the specifications for Granular A, B, SSM, HL and concrete.

Selected Sand and Gravel Resource Area 5 has possible aggregate resources of 9.8 million tonnes. This is based on an available resource area of 92.2 ha and a deposit thickness of 6 m (Table 3). Areas of this deposit are significantly thicker than 6 m.

Selected Sand and Gravel Resource Area 6

Two beach deposits located in the southeast corner of Tilley Township and along the Archibald – Tupper township boundary have been selected as a resource area of primary significance. Both of these areas are located immediately beside the Highway 17 corridor.

Previous MTO test results (Pit No. 54) from the southern most beach deposit indicate a coarse aggregate content of 64.7%, with 34.9% sand and 0.4% fines. Petrographic Numbers are acceptable for granular, 16 mm crushed, HL and concrete. Large clasts range in size from 15 to 25 cm. The aggregate material from this selected resource area should be acceptable for the production of Granular A, B, SSM and HL.

Selected Sand and Gravel Resource Area 6 occupies a total of 121.2 ha. Cultural constraints and previous extraction activity reduces the possible aggregate resource area to 95.2 ha. Assuming a deposit thickness of 6 m, possible sand and gravel resources would be 10.1 million tonnes (Table 3). Houses have been built on the east side of Highway 17 in these 2 areas and as a result sterilization of part of these deposits has taken place. There is still excellent quality aggregate material available for extraction in both of these deposits.

Selected Sand and Gravel Resource Area 7

Two beach deposits located in the northwest corner of Tupper Township and the northeast part of Havilland Township have been selected as a resource area of primary significance. Both of these areas are located immediately east of the Highway 17 corridor.

Gradation results, from a representative sample in the southern beach deposit (Pit No. 86), indicates a coarse aggregate content of 48.7%, with 50.9% sand and 0.4% fines. The large clast size ranges from 15 to 24 cm. The aggregate material in this resource area should be acceptable for the production of Granular A, B, SSM and HL. Selection and blending may be required.

Selected Sand and Gravel Resource Area 7 occupies a total of 159.3 ha. Cultural constraints and previous extraction activity reduce the possible resource area to 127.6 ha. Possible aggregate resources are estimated at 13.6 million tonnes, assuming an average deposit thickness of 6 m (Table 3). Wolf Lake road provides access through the southern beach deposit while a forest access or private road traverses the northern beach deposit.

Selected Sand and Gravel Resource Area 8 (Map 1B)

Selected Sand and Gravel Resource Area 8 is a large outwash deposit located in the west-central part of Deroche Township. The deposit is located along the Highway 556 corridor and could provide aggregate material for maintenance and reconstruction of this road. Aggregate material could also be used for the Searchmont area, to maintain the Algoma Central railway bed, transported westward to the Highway 17 corridor or for the maintenance of other local roads.

Previous MTO test results for Pit No. 21 indicate a coarse aggregate content of 60.3%, with 39.0% sand and 0.7% fines. Petrographic Numbers were 100.0 for granular and 16 mm crushed and 109.2 for HL and concrete. Magnesium sulphate test values are 2.7% for coarse aggregate and 4.6% for fine aggregate. The Los Angeles abrasion results indicate a 18.9% loss (Table 9). The aggregate material from this deposit should be acceptable for the production of Granular A, B, SSM, HL4 (CA) and HL8. HL4 (FA) could be produced with selection and blending.

Selected Sand and Gravel Resource Area 8 has a possible resource area of 252.7 ha after cultural constraints and previous extraction activity have been considered. The possible aggregate resources available, based on a conservative deposit thickness of 6 m, is 26.8 million tonnes (Table 3).

Selected Sand and Gravel Resource Area 9

Selected resource area 9 is an outwash deposit located at the intersection of highways 556 and 532 in Hodgins Township. Transportation of aggregate material from this selected area back to the Highway 17 corridor would be too expensive, particularly since good aggregate resources exist along the Highway 17 corridor. Material from this deposit could however, be used to maintain the local highways, hauled into Searchmont, used to maintain the railway bed or used to maintain other local gravel roads.

MTO operate a pit at Pit No. 30. Previous test results indicate a coarse aggregate content of 71.9%, with 25.7% sand and 0.5% fines. Petrographic Numbers were 102.0 for granular and 16 mm crushed and 109.1 for HL and concrete. Los Angeles abrasion results were 17.4% loss. Layers of silty fine sand, silt and clay were noted during field observations.

Test results from a representative sample (EL-SS-2) collected at the north end of this deposit indicate a coarse aggregate content of 44.8%, with 54.1% sand and 1.1% fines. Aggregate material from this selected area could meet the specifications for Granular A, B, SSM and HL. Blending and sand control may be required.

Selected Sand and Gravel Resource Area 9 has possible aggregate resources of 6.1 million tonnes base on an

conservative average deposit thickness of 6 m. Pit faces at Pit No. 30 were significantly greater than 6 m. The possible resource area is 57.4 ha after cultural constraints and previous extraction activity have been considered (Table 3).

Selected Sand and Gravel Resource Area 10

The final selected resource area of primary significance is an outwash deposit located in the southern part of Duncan Township. Three abandoned pits (Pit Nos. 50, 51 and 52) have been developed within this deposit and faces in all 3 pits expose good quality aggregate material. Transportation to this selected resource area is provided by a forest access road.

Test results from a representative sample collected from Pit No. 51 indicate a coarse aggregate content of 55.2%, with 44.0% sand and 0.8% fines. Based solely on the gradation results, this aggregate deposit would appear suitable for the production of Granular A, B, SSM and lower-specification HL.

Selected Sand and Gravel Resource Area 10 occupies a total of 60.0 ha with 48.6 ha available for possible resource development. Assuming a deposit thickness of 6 m, possible aggregate resources would be 5.2 million tonnes (Table 3). The deposit could supply good quality aggregate material to the Highway 17 corridor and other roads located to the south.

Secondary Sand and Gravel Resources

MAP 1A – BATCHAWANA BAY MAP SHEET

In the northwest corner of Herrick Township a glaciolacustrine beach deposit has been designated as a sand and gravel deposit of secondary significance. This deposit is located immediately adjacent to Highway 17 and part of the deposit is located in Pancake Bay Provincial Park. This deposit has been utilized in the past by the Ministry of Transportation, and previous MTO results indicate a coarse aggregate content of between 56.3 and 67.3%. The fines content varies from 0 to 4.0%. Pit No. 1 has been developed in this deposit area. The main limitation to the aggregate material located in this deposit is the high Petrographic Numbers. PN values in the range of 227.4 and 242.9 for granular and 16 mm crushed have been obtained from this deposit (Table 9).

A large beach deposit located in central Herrick Township has been selected as a resource of secondary significance. Good quality aggregate material is available in this deposit and access to Highway 17 is provided by a forest access road and Highway 563. Test results from Pit No. 6 have already been discussed previously in this report. This beach deposit has not been selected at the primary level because the deposit is shallow.

A beach deposit located north of Highway 17, along the northern edge of the Herrick – Fisher township boundary, has been selected as a resource of secondary significance. A representative sample taken from Pit No. 10 indicates a coarse aggregate fraction of 30.0%, with 68.9% sand and only 1.0% fines. Access to this deposit is provided by a well-maintained forest access road.

A series of small beach deposits in Tilley Township, located to either side of Highway 17, have been selected as aggregate resource areas of secondary significance. An MTO pit (Pit No. 26) in one of these beach deposits has been developed and much of the material from this deposit has been utilized. Previous gradation results for this area indicate 46.7% coarse material, with 52.5% sand and 0.8% fines (Table 9).

A small outwash deposit located in central Tilley Township has been selected at the secondary level. This deposit is located immediately north of a forest access road. Previous gradation results from Pit No. 25 indicate 57.6% coarse material, with 36.8% sand and 5.6% fines. This deposit could provide material to the Highway 17 corridor since the highway is within 5 km of the deposit. The deposit is quite variable; some sections were quite coarse while other areas of the pit had layers of silt and clay. Selection, sand control and blending may be required.

An outwash deposit located in central Tupper Township has been selected as an aggregate resource area of secondary significance. Test results from Pit No. 62, located in this deposit, indicate a coarse aggregate content of 48.6%, 50.6% sand and 0.8% fines (Figures 3A and 3B). Petrographic Numbers are 103.7 for granular and 16 mm crushed and 109.2 for HL and concrete (Table 9). If this deposit had been located closer to Highway 17, it would have been designated as a primary deposit. In addition to the long haul and the roughness of Wolf Lake road, bridges would have to be upgraded and built.

A large beach deposit located in Havilland Township has been designated as an aggregate resource of secondary significance. The coarse aggregate content of this deposit is greater than 50% (Pit 80). Water well data indicates sand and gravel underlying a thin layer of sand in the northern portion of this deposit. Numerous cottages are located along the shoreline so a portion of this deposit would be unavailable for resource development. Material could be transported back to the Highway 17 corridor.

Other isolated sand and gravel resources are available in the study area. For example, Pit No. 14 in Fisher Township is located in an area that has been mapped and identified as lacustrine plain. Within this plain, large, well-developed beach ridges/strands are noticeable. Pit No. 14 is located in one of these beach ridges and gradation results for this pit indicates a coarse aggregate content of 61.5%, with 38.0% sand and only 0.5% fines. This is excellent material that could be used for local road improvements and for maintenance on Highway 17.

MAP 1B – ECHO LAKE MAP SHEET

Outwash deposits scattered throughout the map sheet have been selected at the secondary level of significance. These deposits contain excellent aggregate material as is demonstrated by gradation results shown by the texture symbols on Map 1B. The coarse aggregate content for many of these deposits range from 35.5% to 65.3%. The fine aggregate content ranges from 0.1 to 1.3%. Petrographic Numbers, Los Angeles Abrasion, and Magnesium Suphate test results for these areas are all acceptable.

Aggregate material from these deposits should be suitable for the production of Granular A, B, SSM and HL. The quantity of material available would be quite large based on the extent of some of these deposits (e.g., northeast corner of Gaudette Township and along the Garden and Echo rivers). In many cases, these outwash deposits would be selected at the primary level if they were closer to a potential market area and the transportation links to these markets were better. Many small bridges would have to be built or upgraded in order to provide a transportation corridor to the market area. These deposits are excellent for maintaining local roads.

BEDROCK GEOLOGY

The bedrock in the study area is complex, consisting of a wide variety of rock units. The study area includes Precambrian rocks from both the Superior and Southern Structural Provinces (Map 2).

The oldest rocks in the project area are the Archean metavolcanics and metasediments which are estimated to have formed more than 2600 million years ago. These rocks have been mapped as unsubdivided units of mafic to intermediate volcanic flows and minor interflow metasediments (Giblin and Leahy 1978). They are schistose or gneissic, indicating that they have undergone extensive deformation.

A large part of the study area is underlain by the massive felsic plutonic rocks of the Algoma Plutonic Domain of the Abitibi Subprovince. This large batholitic complex consists of: coarse, porphyritic, leucocratic granite; quartz monzonite; granodiorite; and migmatitic rocks (Jackson and Fyon 1991).

Rocks of the Huronian Supergroup of the Southern Structural Province underlie the southeastern and extreme northwestern parts of the study area. They have been described as a thick sequence of detrital sedimentary rocks deposited on an eroded Archean basement. Lithologies present include quartzites, arkoses, conglomerates, limestones, greywackes and calcareous siltstones. After deposition, the Huronian sequence of rocks was subjected to folding and metamorphism and intrusion by Nipissing age rocks.

The youngest bedrock unit in the area is the Jacobsville Formation. It underlies much of shoreline region surrounding Batchawana Bay and consists of flat-lying red sandstone with lesser amounts of siltstone, shale and conglomerate. Texturally, the Jacobsville Formation is primarily a moderately to well-sorted, medium-grained, quartz-rich red sandstone with mottled grey reduction patches and seams. Russell (1987) considered the Jacobsville sandstone to be a fluvial deposit, perhaps of alluvial fan origin. Trough cross-bedding indicates paleocurrent directions toward the Lake Superior basin. Ripple marks are common on silty beds. The true bedding, although often obscured by cross-bedding, is nearly horizontal in most locations; however, almost vertical dips are known to occur near major faults (Russell 1987).

In the absence of fossils, the Jacobsville Formation was for many years considered to be of Lower to Middle Cambrian age (530-570 Ma, Giblin and Leahy 1978). Recent paleomagnetic studies suggest an age of deposition of approximately 1100 Ma. The Geology of Ontario (1991) designates the Jacobsville Formation as Precambrian (Mesoproterozoic).

The areas of highest mineral potential coincide with the belts of metavolcanic and metasedimentary rocks. Although there are no active mines in the study area, important occurrences of copper, lead, zinc, silver and gold have been discovered in the past. Areas of prime interest occur in the townships of Aweres, Duncan, Jarvis, Deroche and VanKoughnet in the southern part of the area, and Ryan and Palmer just to the northwest of the project area. Bennett et al 1975; Bennett, Sawitzky and Whittaker 1976a, 1976b; Born, Worona and Stephenson 1986; Born 1987; and Giblin 1968a, 1968b all provide more detail on the bedrock geology of the study area.

BEDROCK SUITABILITY

The gneissic and granitic rocks in the report area are a potential source of quality aggregate. Having stated this, Precambrian bedrock may exhibit wide variations with respect to aggregate quality over relatively short distances. Precambrian rocks are usually hard and relatively homogeneous, but brittle varieties can occur and should be avoided in aggregate use. Massive, coarse-grained felsic plutonic and gneissic rocks with high mica, feldspar and quartz content may have bonding problems. The smooth cleavage and fracture surfaces of the minerals hinder the adhesion of asphalt and Portland cement concrete mixes. This problem can often be circumvented by weathering the rocks for a period of time in stockpiles or by adding chemicals (anti-stripping agents) that erode the smooth surfaces and allow better adhesion.

Rogers (1985) reports that some granitic rocks can slowly react with alkalies from Portland cement concrete, resulting in concrete deterioration. Although the Precambrian bedrock in the area may meet MTO specifications for concrete aggregate, it may not be accepted by the MTO for use in Portland cement concrete which will be exposed to de-icing salts.

A granite sample (BB-SS-2, Map 1A) was collected as part of this study and submitted for a wide range of tests. The test results indicate a PN for granular and 16 mm crushed of 100.0 and 100.0 for hot mix and concrete (Table 9). Coarse aggregate Micro Deval result for this sample

was 4.6%. The mortar bar expansion results were 0.053% for a 14 day period.

Huronian Supergroup rocks were subject to folding and metamorphism. Because of extensive mineral and structural alterations, certain lithologies may be alkali-silica reactive. For example, greywackes and argillites may contain coarse-grained quartz with a deformed crystal lattice. This type of quartz is an alkali-silica reactive mineral, meaning that the quartz is likely to react with alkalies from the cement paste and may cause expansion and cracking of the concrete (Rogers 1985). This characteristic may restrict the use of these rocks to road construction applications only. Certain lithologies within the Huronian sequence have been found excessively hard and could not be economically quarried elsewhere. There is no evidence of any bedrock quarrying for road-building or construction use within the study area.

The Nipissing diabase has proven to be an excellent source of aggregate material. The diabase is being quarried near Bruce Mines for transport to southern Ontario and the United States. Test results for the Nipissing diabase from the north shore of Lake Huron are listed in Table 9. Any proposed quarry location should be thoroughly tested before extraction commences.

The Jacobsville Formation is not suitable for use as load-bearing and construction aggregate because it is weak, porous and weathers to sand-sized material. It has been, however, a traditional source of building and decorative stone in areas where it outcrops and more recently it was used as compact fill on the Great Lakes Power Development Project. Although the Jacobsville Formation sandstone was used locally as a building stone, its inherent weakness and poor durability render it unsuitable for modern building techniques where stone is used mainly as a facing over steel girders. Its attractive color and thin bedding make this sandstone desirable for flagstone and decorative stone. Quarries currently located in the area are predominantly associated with previous mining activity and are not related to the production of aggregate products.

SUMMARY

Ten Selected Sand and Gravel Resource Areas have been identified within the study area. These areas occupy a total of 1747 ha. Cultural constraints and previous extractive activities reduce the possible resource area to 1523 ha. Total possible aggregate resources for the study area are 161.7 million tonnes (Table 3). The majority of these selected areas are glaciolacustrine beach or glaciofluvial outwash deposits. Many of the selected areas are located close to the Highway 17 corridor.

Secondary and tertiary sand and gravel deposits add significantly to the overall aggregate resources in the area. Large outwash deposits contain significant amounts of good quality aggregate material. Unfortunately, a number of these resources are located well away from potential markets and are not accessible by transportation routes.

Within the report area, considerable latitude exists in choosing potential sites for bedrock extraction, particularly within the felsic intrusives, granitic gneisses and Nipissing diabase, as there are extensive areas where bedrock is exposed at or near surface. Any site proposed for quarry development should be thoroughly tested before extraction commences.

Enquiries regarding the Aggregate Resources Inventory of the Echo Lake to Batchawana Bay Area, may be directed to the Sedimentary Geoscience Section, Ontario Geological Survey, Ministry of Northern Development and Mines, 7th Floor, 933 Ramsey Lake Road, Sudbury, Ontario, P3E 6B5; the Resident Geologist Office, Ministry of Northern Development and Mines, Sault Ste. Marie, Ontario; or the Ministry of Natural Resources, Sudbury, Ontario.

TABLE 1 - TOTAL SAND AND GRAVEL RESOURCES
ECHO LAKE TO BATCHAWANA BAY AREA

1 Class No.	2 Deposit Type	3 Areal Extent (Hectares)	4 Original Tonnage (Million Tonnes)*
Map 1A - Batchawana Bay Map Sheet			
1	G-LB	1223	129.9
	G-OW	455	48.3
	S-LB	287	30.5
	S-OW	605	64.3
	S-LP	4547	482.9
	S-AL	1580	167.8
	S-IC	8	0.8
2	G-LB	1448	115.3
	G-OW	765	60.9
	S-LB	759	60.5
	S-OW	137	10.9
	S-LP	1456	115.9
3	G-LB	568	20.1
	S-OW	41	1.5
Subtotal		**13879**	**1309.6**
Map 1B - Echo Lake Map Sheet			
1	G-OW	1909	202.7
	S-LP	125	13.3
	S-AL	3859	409.8
2	G-LB	19	1.5
	G-OW	4351	346.6
	G-IC	59	4.7
	S-OW	1197	95.3
	S-LP	470	37.4
3	G-OW	618	21.9
	S-OW	13	0.5
Subtotal		**12620**	**1133.7**
STUDY AREA TOTAL		**26499**	**2443.3**

* Minor variations in all tables are caused by the rounding of data.

The above figures represent a comprehensive inventory of all granular materials in the map area. Some of the material included in the estimate has no aggregate potential and some is unavailable for extraction due to land use restrictions.

TABLE 2 - SAND AND GRAVEL PITS
Batchawana Bay Map Sheet

Pit No.	Owner/Operator	Licenced Area (Hectares)	Face Height (Metres)	% Gravel	Remarks
Herrick Township					
Unlicenced Pits					
1	-	-	2 - 3	40 - 60	pit overgrown, high PN values
2	-	-	3 - 5	40 - 50	part of large beach deposit
3	-	-	1 - 2	40 - 50	shallow part of large beach deposit
4	-	-	1 - 2	30 - 50	shallow part of large beach deposit
5	-	-	1 - 1.5	30 - 50	shallow part of large beach deposit
6	-	-	1 - 2	40 - 60	pit floor is quite moist (water table)
7	-	-	1	30 - 50	bedrock and water along pit floor
8	-	-	4 - 5	40 - 60	part of large beach deposit
Fisher Township					
Licenced Pits					
9	Astina Development	-	2 - 4	45 - 65	part of large beach deposit
Unlicenced Pits					
10	-	-	2 - 3	25 - 35	beach deposit, mainly medium to coarse sand and fine gravel
11	-	-	1 - 1.5	5 - 10	predominantly a sand source
12	-	-	2 - 3	30 - 40	northern part of beach deposit
13	-	-	2 - 3	20 - 30	not as coarse as Pit No. 8
14	-	-	4 - 5	40 - 50	beach shoreline on glaciolacustrine plain deposit
15	-	-	2 - 3	0 - 10	mainly sand, now a pond area
16	-	-	2 - 3	0 - 10	predominantly a sand source
17	-	-	2 - 3	0 - 10	predominantly a sand source
18	-	-	2 - 3	10 - 15	predominantly a sand source
19	-	-	2 - 3	45 - 65	small beach deposit
20	-	-	3 - 4	35 - 50	similar to Pit No. 19
Tilley Township					
Licenced Pits					
21	461554 Ontario Ltd.	137.00	-	-	Part of Begley copper showing
Unlicenced Pits					
22	-	-	2 - 3	-	pit located in till material
23	-	-	5 - 7	10 - 20	mainly sand, located immediately north of Highway 17
24	-	-	1 - 1.5	-	pit located in till material
25	-	-	8 - 10	variable	pockets of good material mixed with silt and clay
26	-	-	2 - 3	30 - 40	beach deposit, good deal of material has been removed
27	-	-	2 - 3	35 - 50	pit badly overgrown
28	-	-	3 - 4	0 - 10	predominantly a sand source

TABLE 2 - SAND AND GRAVEL PITS
Batchawana Bay Map Sheet

Pit No.	Owner/Operator	Licenced Area (Hectares)	Face Height (Metres)	% Gravel	Remarks
Archibald Township					
Unlicenced Pits					
29	-	-	1 - 1.5	0 - 10	mainly medium to coarse sand
30	-	-	1 - 2	10 - 20	more coarse material than Pit No. 29
31	-	-	1 - 2	10 - 20	similar to Pit No. 30
32	-	-	1 - 1.5	10 - 20	similar to Pit No. 30
33	-	-	1 - 1.5	10 - 20	similar to Pit No. 30
34	-	-	4 - 6	60 - 70	pit located in large outwash deposit
35	-	-	2 - 3	50 - 60	similar to Pit No. 34
36	-	-	3 - 4	-	pit located in till material
37	-	-	2 - 3	10 - 20	mainly medium to coarse sand
38	-	-	4 - 6	10 - 20	mainly medium to coarse sand
39	-	-	2 - 3	-	pit located in till material
40	-	-	3 - 5	-	pit located in till material
41	-	-	1 - 3	-	pit located in till material
42	-	-	1 - 2	-	pit located in till material
43	-	-	1 - 1.5	10 - 20	mainly medium to coarse sand
44	-	-	3 - 4	-	pit located in till material
45	-	-	2 - 4	10 - 20	mainly medium to coarse sand
46	-	-	2 - 3	10 - 20	mainly medium to coarse sand
47	-	-	2 - 4	-	pit located in till material
48	-	-	2 - 3	-	pit located in till material
49	-	-	4 - 5	-	till material, boulders present
50	-	-	1 - 2	-	till material, boulders present
51	-	-	4 - 6	-	till material, boulders present
52	-	-	1 - 2	-	pit located in till material
53	-	-	1 - 2	-	pit located in till material
54	-	-	2 - 3	45 - 65	pit located in beach deposit
Tupper Township					
Unlicenced Pits					
55	-	-	2 - 3	30 - 50	good material, deposit may be shallow
56	-	-	2 - 3	30 - 50	similar to Pit No. 55
57	-	-	2 - 3	30 - 50	similar to Pit No. 55
58	-	-	1 - 2	-	pit located in till material
59	-	-	2 - 4	-	till material, boulders present
60	-	-	1 - 2	10 - 20	mainly medium sand, fine gravel
61	-	-	1 - 2	-	pit located in till material
62	-	-	8 - 10	variable	pit located in outwash deposit
63	-	-	2 - 3	-	pit located in till material
64	-	-	1 - 2	20 - 40	medium to coarse sand with gravel
65	-	-	1 - 2	20 - 40	similar to Pit No. 64
66	-	-	1 - 2.5	20 - 40	similar to Pit No. 64
67	-	-	2 - 3	20 - 40	similar to Pit No. 64

TABLE 2 - SAND AND GRAVEL PITS
Batchawana Bay Map Sheet

Pit No.	Owner/Operator	Licenced Area (Hectares)	Face Height (Metres)	% Gravel	Remarks
68	-	-	2.5 - 3.5	20 - 40	similar to Pit No. 64
69	-	-	1 - 2	10 - 20	medium to coarse sand with gravel
70	-	-	2 - 3	20 - 40	medium to coarse sand with gravel
71	-	-	4 - 6	-	till material, boulders present
72	-	-	3 - 4	35 - 50	medium to coarse sand with gravel
73	-	-	3 - 4	-	till material, boulders present
74	-	-	3 - 4	-	till material, boulders present
75	-	-	4 - 5	-	till material, boulders present
76	-	-	1 - 2	-	till material, boulders present
Havilland Township					
Licenced Pits					
77	John McCauley	32.40	2 - 4	0 - 10	predominantly a sand source
Unlicenced Pits					
78	-	-	1 - 1.5	10 - 20	rounded pebbles in a fine sand matrix
79	-	-	1 - 3	10 - 20	similar to Pit No. 78
80	-	-	1 - 3	10 - 20	similar to Pit No. 78
81	-	-	1 - 3	0 - 10	predominantly a sand source
82	-	-	4 - 7	10 - 20	predominantly a sand source
83	-	-	5 - 7	0 - 10	mainly sand with silt and clay layers
84	-	-	1 - 2	5 - 15	mainly sand, wet pit floor, shallow beach deposit
85	-	-	1 - 2	5 - 15	similar to Pit No. 84
86	-	-	1 - 2	30 - 50	pit located in beach deposit
Ley Township					
Licenced Pits					
87	Gerard Otis	15.00	2 - 3	20 - 30	pit located in beach deposit
88	Serena Development Inc.	50.00	3 - 4	40 - 60	material is quite coarse, most large clasts are Jacobsville Formation sandstone
Unlicenced Pits					
89	-	-	1 - 1.5	20 - 40	pit located in beach deposit
90	-	-	1 - 1.5	20 - 40	pit located in beach deposit, wet pit floor
91	-	-	1 - 2	10 - 30	beach deposit, bedrock and water in pit floor
92	-	-	1 - 2	10 - 30	similar to Pit No. 91
93	-	-	1 - 2	30 - 50	beach deposit, a lot of garbage in pit area
94	-	-	2 - 3	15 - 25	mainly medium to coarse sand

TABLE 2 - SAND AND GRAVEL PITS
Echo Lake Map Map Sheet

Pit No.	Owner/Operator	Licenced Area (Hectares)	Face Height (Metres)	% Gravel	Remarks
Shields Township					
Unlicenced Pits					
1	-	-	1.5 - 2.5	10 - 20	shallow outwash deposit, bedrock and water in pit floor
2	-	-	variable	variable	pit located in outwash deposit
3	-	-	1 - 1.5	10 - 20	medium to coarse sand with gravel
4	-	-	1 - 1.5	10 - 20	outwash deposit, pit overgrown
5	-	-	5 - 7	40 - 60	outwash deposit, good aggregate material
6	-	-	4 - 6	40 - 60	similar to Pit No. 5
7	-	-	6 - 8	40 - 60	similar to Pit No. 5
8	-	-	3 - 4	20 - 30	outwash deposit
9	-	-	2 - 3	20 - 30	medium to coarse sand with gravel
10	-	-	variable	variable	outwash material, also till material present
Gaudette Township					
Unlicenced Pits					
11	-	-	1	5 - 15	medium to coarse sand with gravel
12	-	-	2 - 3	5 - 15	similar to Pit No. 11
13	-	-	2 - 3	5 - 15	similar to Pit No. 11
14	-	-	1 - 2.5	5 - 15	medium to coarse sand with gravel
15	-	-	2 - 3	30 - 50	pit located in outwash deposit
16	-	-	2 - 3	30 - 50	pit located in outwash deposit
17	-	-	1	40 - 60	pit located in outwash deposit
18	-	-	1	40 - 60	pit located in outwash deposit
19	-	-	4 - 6	40 - 60	pit located in outwash deposit
20	-	-	5 - 7	50 - 70	pit located in outwash deposit
Deroche Township					
Unlicenced Pits					
21	-	-	6 - 9	40 - 60	large pit located in outwash deposit
22	-	-	1	-	till material, bedrock and water in pit floor
23	-	-	2 - 3	0 - 10	mainly fine to medium sand
24	-	-	3 - 4	-	till material, boulders present
25	-	-	2 - 3	-	till material, boulders present
26	-	-	3 - 4	-	till material, boulders present
27	-	-	1 - 2	-	till material, some fine to medium sand, lots of bedrock around
28	-	-	1 - 2	-	till material
29	-	-	1 - 2	-	similar to Pit No. 27
Hodgins Township					
Licenced Pits					
30	Nick Olar	16.2	15 - 18	variable	material is variable, ranging from silt and fine sand to coarse aggregate material

TABLE 2 - SAND AND GRAVEL PITS
Echo Lake Map Map Sheet

Pit No.	Owner/Operator	Licenced Area (Hectares)	Face Height (Metres)	% Gravel	Remarks
Unlicenced Pits					
31	-	-	3 - 5	35 - 55	pit located within community of Searchmont
32	-	-	4 - 6	35 - 55	pit located in outwash deposit
33	-	-	4 - 6	35 - 55	similar to Pit No. 32
34	-	-	5 - 7	30 - 40	coarse sand with fine to medium gravel
35	-	-	1	10 - 20	medium to coarse sand with gravel
36	-	-	3 - 4	30 - 40	pit located in outwash deposit
37	-	-	2 - 3	40 - 50	pit located in outwash deposit, partially rehabilitated/overgrown
37B	-	-	2 - 3	40 - 50	similar to Pit No. 37
Jarvis Township					
Unlicenced Pits					
38	-	-	1	30 - 40	small outwash deposit, water in pit floor
Anderson Township					
Unlicenced Pits					
39	-	-	4 - 5	20 - 30	small outwash deposit, mainly medium to coarse sand, bedrock in pit floor
40	-	-	7 - 9	30 - 40	outwash deposit, medium to coarse sand with gravel
41	-	-	3 - 4	0 - 10	mainly silty fine to medium sand
Chesley Township					
Unlicenced Pits					
42	-	-	7 - 9	30 - 40	material grades from medium to coarse sand to pebble-cobble
43	-	-	4 - 6	30 - 40	similar to Pit No. 42
44	-	-	4 - 5	30 - 40	also similar to Pit No. 42
45	-	-	2 - 3	25 - 35	medium to coarse sand with gravel
Duncan Township					
Unlicenced Pits					
46	-	-	3 - 4	0 - 10	medium to coarse sand with some gravel
47	-	-	3 - 4	20 - 30	medium to coarse sand with gravel
48	-	-	5 - 7	40 - 50	outwash deposit, good crushable material
49	-	-	4 - 5	20 - 30	medium to coarse sand with gravel
50	-	-	5 - 6	0 - 5	mainly silty fine to medium sand
51	-	-	5 - 7	20 - 30	similar to Pit No. 50 but with more coarse material
52	-	-	3 - 4	20 - 30	similar to Pit No. 51
53	-	-	1 - 2	0 - 10	medium to coarse sand with pea gravel
54	-	-	8 - 10	40 - 60	small ice-contact deposit - excellent material
55	-	-	1 - 2	0 - 10	medium to coarse sand with some gravel
56	-	-	3 - 5	35 - 50	medium to coarse sand with gravel

TABLE 2 - SAND AND GRAVEL PITS
Echo Lake Map Map Sheet

Pit No.	Owner/Operator	Licenced Area (Hectares)	Face Height (Metres)	% Gravel	Remarks
Kehoe Township					
Unlicenced Pits					
57	-	-	1 - 1.5	0 - 10	small pit, medium to coarse sand with gravel
58	-	-	1 - 1.5	20 - 30	mainly coarse sand
59	-	-	1 - 1.5	20 - 30	similar to Pit No.58
60	-	-	2 - 3	10 - 20	medium to coarse sand with gravel
61	-	-	1.5 - 2.5	-	small till pit, small quarry on property
62	-	-	1 - 2	0 - 10	coarse sand with gravel, bedrock exposed in pit area
63	-	-	1 - 2	-	till material, water in pit floor
64	-	-	1 - 1.5	-	pit located in till material
65	-	-	7 - 10	-	quarry face - rock ridge
66	-	-	1 - 2	-	pit located in till material
67	-	-	1 - 3	-	pit located in till material
68	-	-	2 - 3	-	pit located in till material
69	-	-	2 - 3	variable	small outwash deposit, material varies from silt and clay to gravel, water in pit floor
Chesley Additional Township					
Unlicenced Pits					
70	-	-	7 - 9	30 - 50	outwash deposit, material grades from medium to coarse sand to crushable
71	-	-	4 - 6	30 - 50	similar to Pit No. 70

TABLE 3 - SELECTED SAND AND GRAVEL RESOURCE AREAS
Echo Lake to Batchawana Bay Area

1 Deposit No.	2 Unlicenced Area (Hectares)*	3 Cultural Setback (Hectares)**	4 Extracted Area (Hectares)***	5 Possible Resource Area (Hectares)	6 Estimated Deposit Thickness (Metres)	7 Possible Aggregate Resources**** (Million Tonnes)
1	134.5	4.4	5.7	124.4	6	13.2
2	520.7	0.0	8.1	512.6	6	54.4
3	204.9	16.3	11.3	177.3	6	18.8
4	44.8	0.0	9.7	35.1	6	3.7
5	93.2	0.0	1.0	92.2	6	9.8
6	121.2	16.3	9.7	95.2	6	10.1
7	159.3	18.7	13.0	127.6	6	13.6
8	324.9	65.0	7.2	252.7	6	26.8
9	83.4	19.5	6.5	57.4	6	6.1
10	60.0	6.5	4.9	48.6	6	5.2
Study Area Total						
	1746.9	**146.7**	**77.1**	**1523.1**		**161.7**

Minor variations in all tables are caused by the rounding of data

* Excludes areas licenced under the *Aggregate Resources Act* (1989).

** Cultural setbacks include heavily populated urban areas, roads (including a 100 m wide strip centred on each road), water features (e.g., lakes, streams), 1 ha for individual houses. NOTE: this provides a preliminary and generalized constraint application only. Additional environmental and social constraints will further reduce the deposit area.

*** Extracted area is a rough estimate of areas that are not licenced but largely depleted such as abandoned and wayside pit sites.

**** Further environmental, resource, social and economic constraints will greatly reduce the selected resource quantity realistically available for potential extraction.

TABLE 4 - TOTAL BEDROCK RESOURCES
Echo Lake to Batchawana Bay Area

1 Drift Thickness	2 Formation	3 Estimated Deposit Thickness (Metres)	4 Areal Extent (Hectares)	5 Original Tonnage (Million Tonnes)

Since Precambrian bedrock is so variable (refer to the report), total bedrock resources were not calculated for this area

TABLE 5 - QUARRIES
Echo Lake to Batchawana Bay Area

Quarry No.	Owner/Operator	Licenced Area (Hectares)	Face Height (Metres)	Remarks

TABLE 6 - SELECTED BEDROCK RESOURCES
Echo Lake to Batchawana Bay Area

1 Area No.	2 Depth of Overburden (Metres)	3 Area (Hectares)*	4 Cultural Setbacks (Hectares)**	5 Extracted Area (Hectares)***	6 Possible Resource Area (Hectares)	7 Estimated Workable Thickness (Metres)	8 Possible Bedrock Resources**** (Million Tonnes)

Since Precambrian bedrock can be so variable (refer to the report), there were no selected bedrock resource areas for this area

TABLE 7 - SUMMARY OF TEST HOLE DATA OR SELECTED SAMPLE DATA
Echo Lake to Batchawana Bay Area

- NONE -

TABLE 8 - SUMMARY OF GEOPHYSICAL DATA
Echo Lake to Batchawana Bay Area

- NONE -

TABLE 9 - RESULTS OF AGGREGATE QUALITY TESTS
SAND AND GRAVEL SAMPLES
Echo Lake to Batchawana Bay Area

	COARSE AGGREGATE								FINE AGGREGATE
Sample No.	Petrographic Number Granular & 16 mm Crushed	Petrographic Number Hot Mix & Concrete	Magnesium Sulphate Soundness (% Loss)	Absorption (%)	Los Angeles Abrasion* (% Loss)	Freeze-Thaw (% Loss)	Accelerated Mortar Bar Expansion (% Expansion)	Micro Deval Abrasion (% Loss)	Micro Deval Abrasion (% Loss)
Map 1A - Batchawana Bay Map Sheet									
Pit No. 1	227.4	-	-	-	-	-	-	-	-
	242.9	-	-	-	-	-	-	-	-
Pit No. 2	101.0	127.6	-	-	23	-	-	-	-
Pit No. 6	100.5	113.7	3	2.741	23	2	0.14 (14 Days)	7.5	9.8
Pit No. 8	100.0	112.0	4	2.735	-	1	-	7.5	-
Pit No. 9	102.4	125.7	6	1.430	19	-	-	-	5.4*
Pit No. 26	102.7	121.4	-	-	16	-	-	-	-
Pit No. 34	100.3	102.5	2	2.758	19	-	-	5.6	9.8
Pit No. 54	100.0	101.1	-	-	15	-	-	-	-
Pit No. 62	103.7	109.2	2	2.745	21	1	-	5.2	6.0
BB-SS-2	100.0	100.0	0	-	0	-	0.053 (14 Days)	4.6	-
Map 1B - Echo Lake Map Sheet									
Pit No. 21	100.0	109.2	2.7	-	19	-	-	-	4.6*
Nipissing	100.0	102.0	1	0.234	9	2	0.032	3.4	-
Nipissing	100.0	101.0	1	0.234	16	2	0.046	5.8	-

Note - the quality test data refers strictly to a specific sample. Because of inherent variability of sand and gravel deposits, care should be exercised in extrapolating such information to the rest of the deposit.

* Magnesium sulphate (FA) result

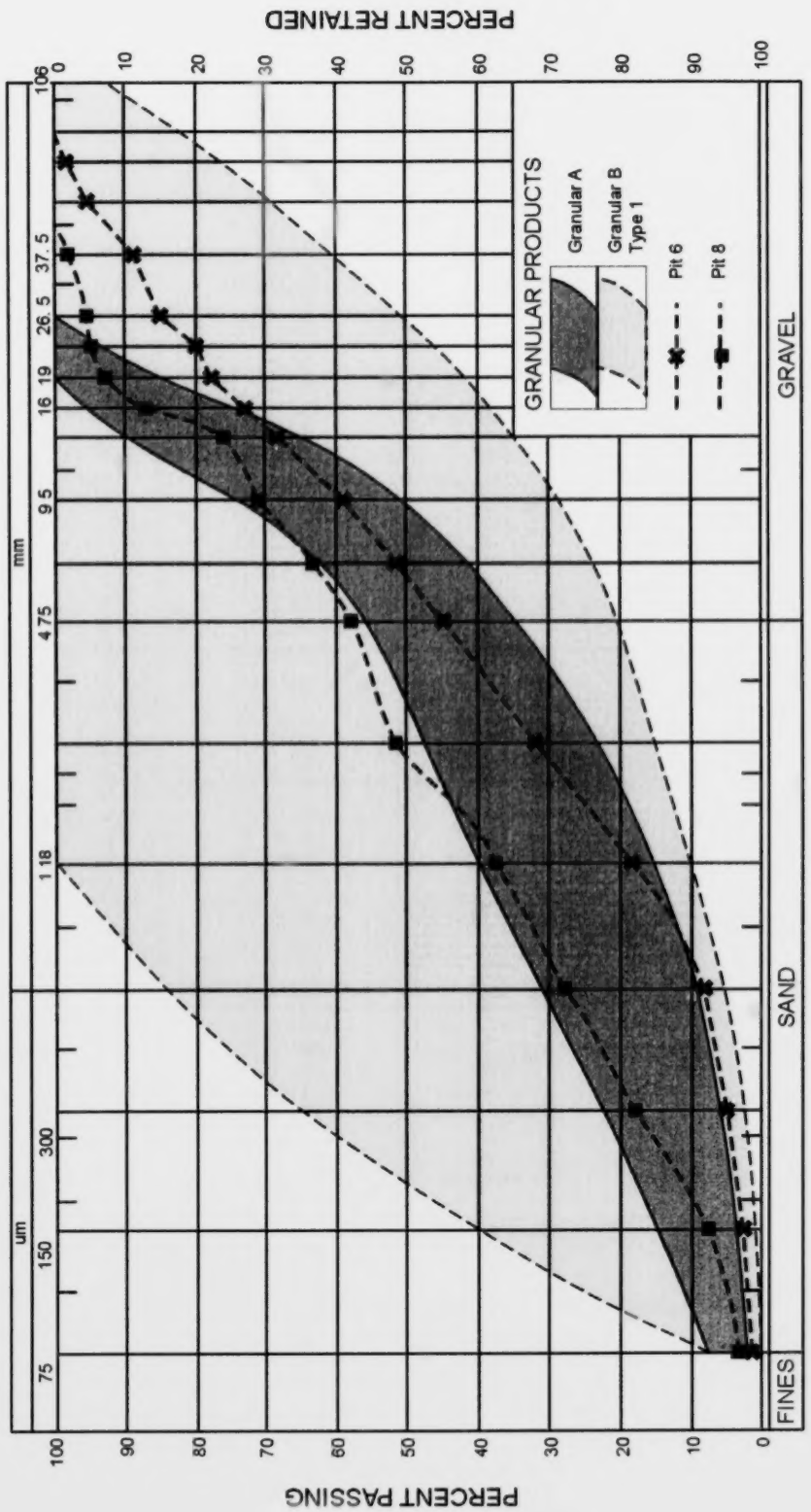


FIGURE 2A AGGREGATE GRADING CURVES,
Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from Ontario Provincial Standard Specifications OPSS 1010, 1988).

NOTE:
Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

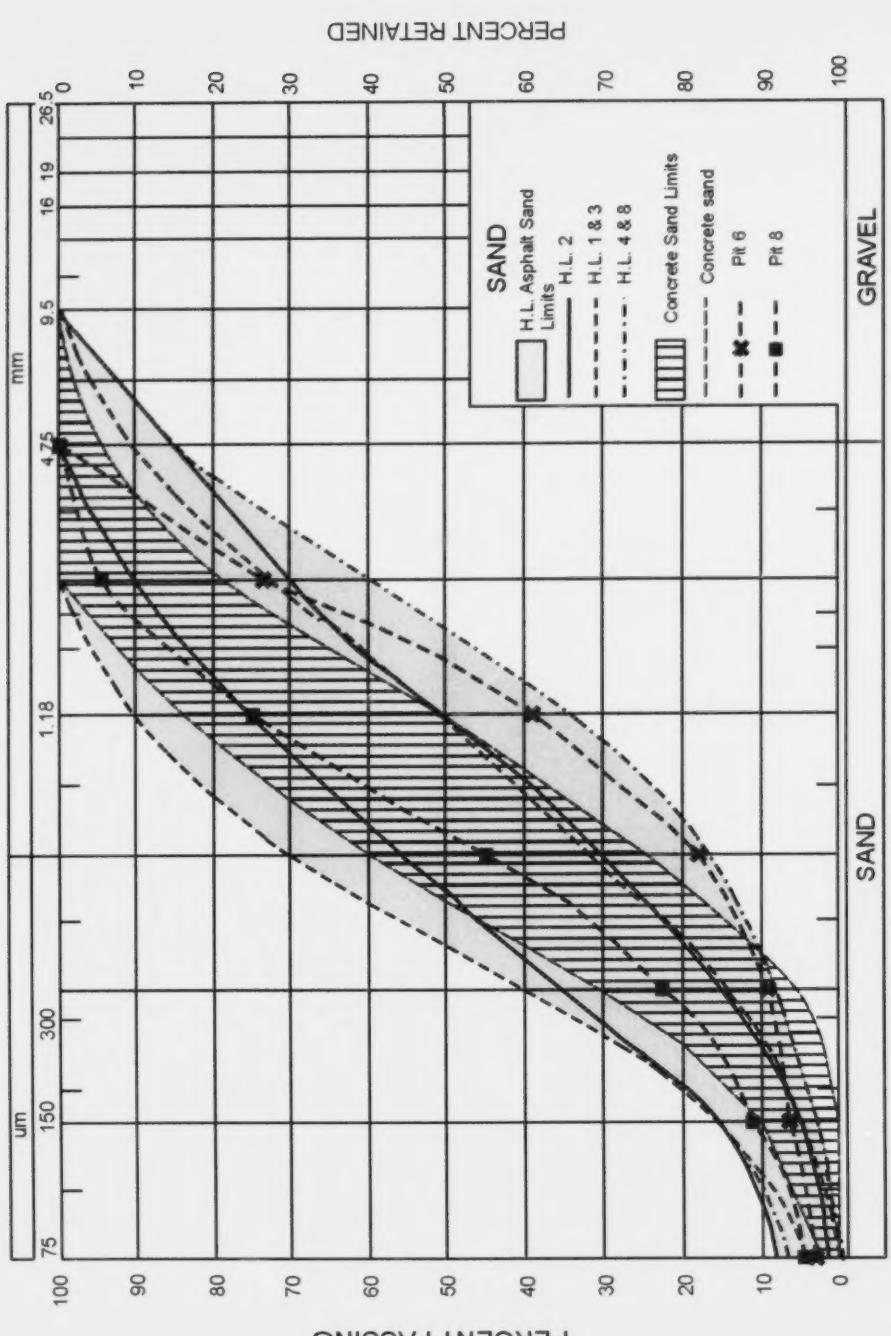


FIGURE 2B AGGREGATE GRADING CURVES,
Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from Ontario Provincial Standard Specifications OPSS 1002, 1988 and 1003, 1988).

NOTE:
Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

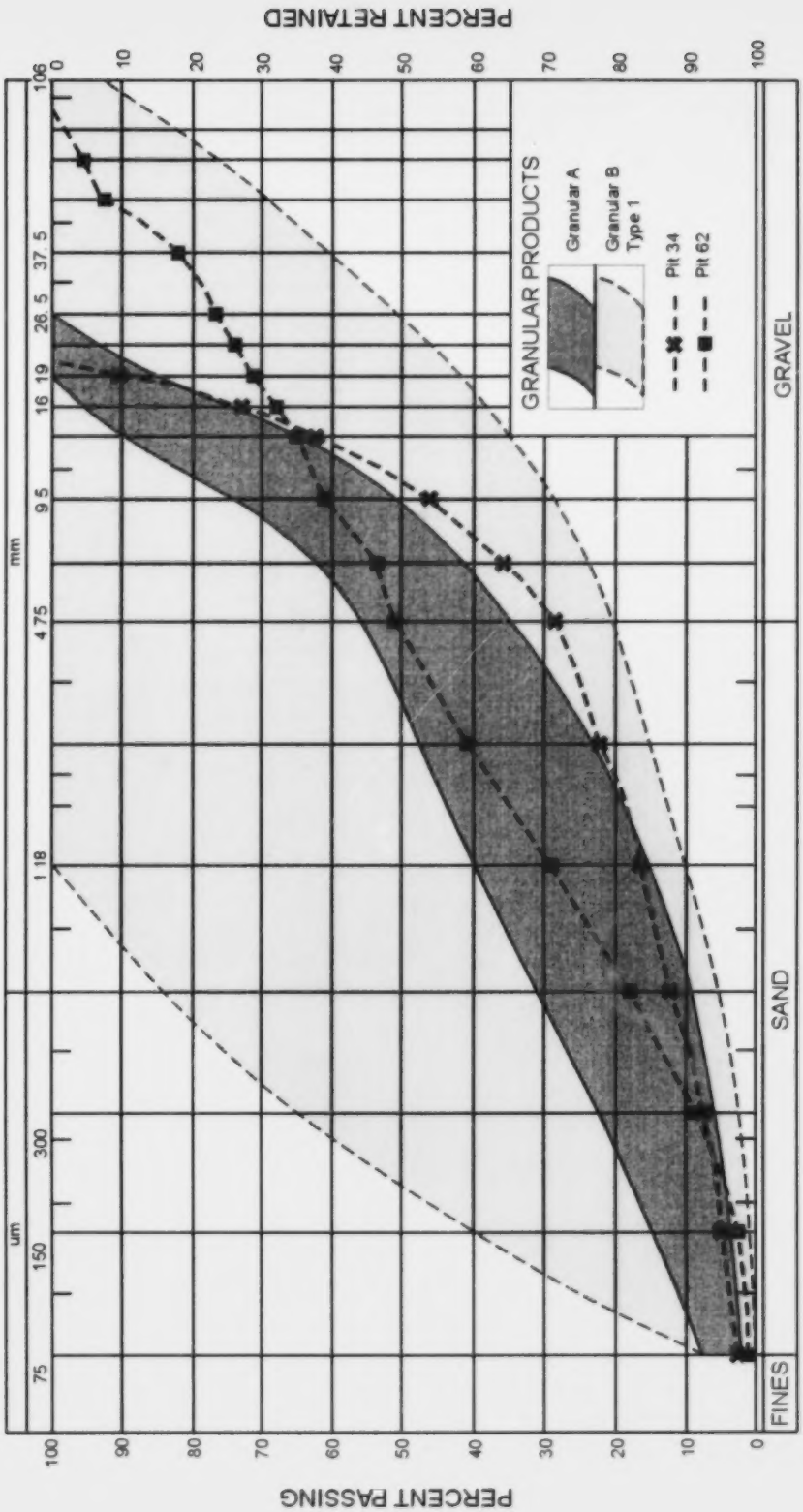


FIGURE3A AGGREGATE GRADING CURVES.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from Ontario Provincial Standard Specifications OPSS 1010, 1988).

NOTE:
Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

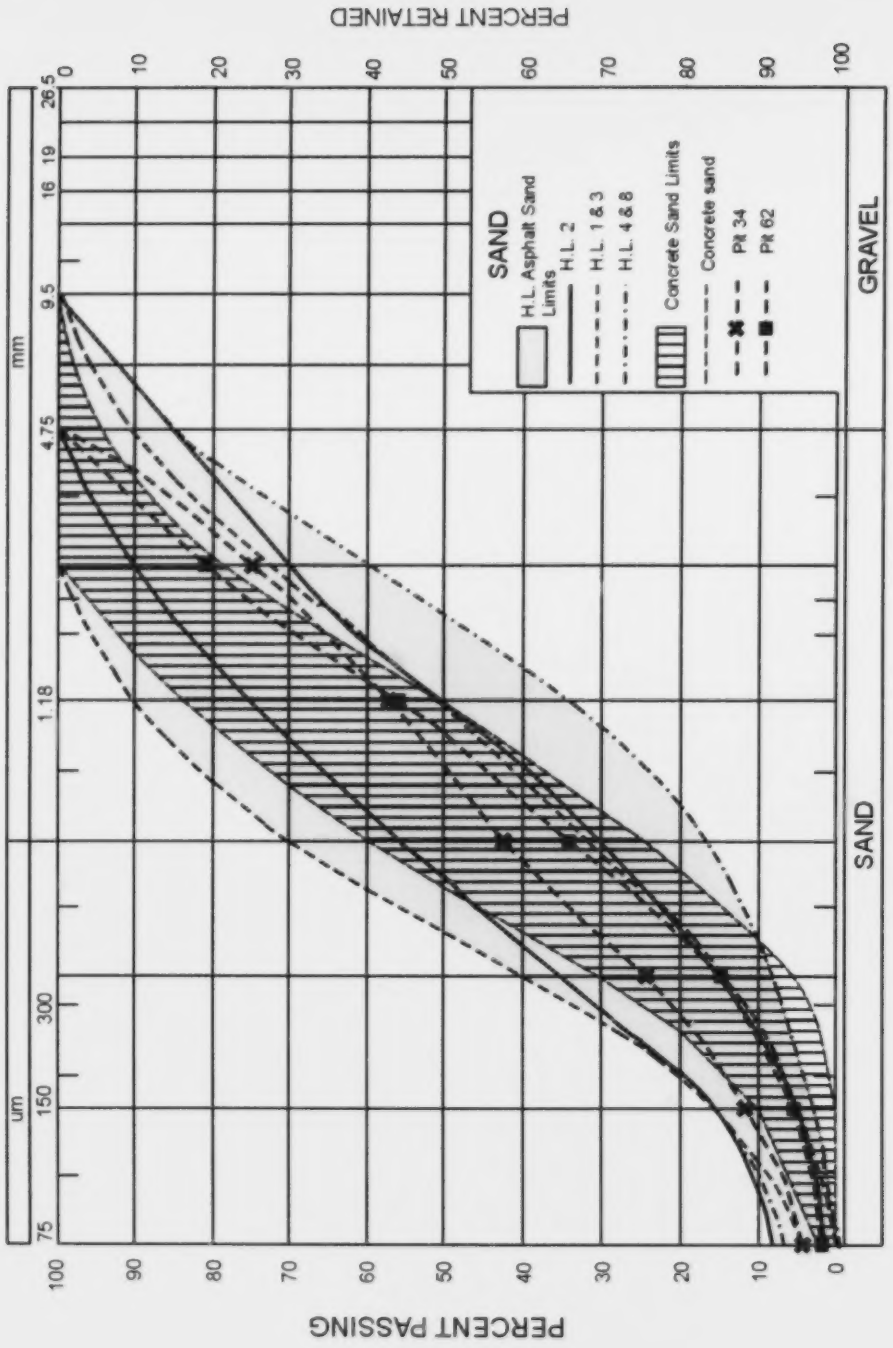


FIGURE 3B AGGREGATE GRADING CURVES,
Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from Ontario Provincial Standard Specifications OPSS 1002, 1988 and 1003, 1988).

NOTE:
Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

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Appendix B - Glossary

Abrasion resistance: Tests such as the Los Angeles abrasion test are used to measure the ability of aggregate to resist crushing and pulverizing under conditions similar to those encountered in processing and use. Measuring resistance is an important component in the evaluation of the quality and prospective uses of aggregate. Hard, durable material is preferred for road building.

Absorption capacity: Related to the porosity of the rock types of which an aggregate is composed. Porous rocks are subject to disintegration when absorbed liquids freeze and thaw, thus decreasing the strength of the aggregate.

Acid-Soluble Chloride Ion Content: This test measures total chloride ion content in concrete and is used to judge the likelihood of re-bar corrosion and susceptibility to deterioration by freeze-thaw in concrete structures. There is a strong positive correlation between chloride ion content and depassivation of reinforcing steel in concrete. Depassivation permits corrosion of the steel in the presence of oxygen and moisture. Chloride ions are contributed mainly by the application of de-icing salts.

Aggregate: Any hard, inert, construction material (sand, gravel, shells, slag, crushed stone or other mineral material) used for mixing in various-sized fragments with a cement or bituminous material to form concrete, mortar, etc., or used alone for road building or other construction. Synonyms include mineral aggregate and granular material.

Aggregate Abrasion Value: This test directly measures the resistance of aggregate to abrasion with silica sand and a steel disk. The higher the value, the lower the resistance to abrasion. For high quality asphalt surface course uses, values of less than 6 are desirable.

Alkali-aggregate reaction: A chemical reaction between the alkalies of Portland cement and certain minerals found in rocks used for aggregate. Alkali-aggregate reactions are undesirable because they can cause expansion and cracking of concrete. Although perfectly suitable for building stone and asphalt applications, alkali-reactive aggregates should be avoided for structural concrete uses.

Beneficiation: Beneficiation of aggregates is a process or combination of processes which improves the quality (physical properties) of a mineral aggregate and is not part of the normal processing for a particular use, such as routine crushing, screening, washing, or classification. Heavy media separation, jigging, or application of special crushers (e.g., "cage mill") are usually considered processes of beneficiation.

Blending: Required in cases of extreme coarseness, fineness, or other irregularities in the gradation of unprocessed aggregate. Blending is done with approved sand-sized aggregate in order to satisfy the gradation requirements of the material.

Bulk Relative Density: The density of a material related to water at 4°C and atmospheric pressure at sea level. An aggregate with low relative density is lighter in weight than one with a high relative density. Low relative density aggregates (less than about 2.5) are often non-durable for many aggregate uses.

Cambrian: The first period of the Paleozoic Era, thought to have covered the time between 570 and 505 million years age. The Cambrian precedes the Ordovician Period.

Chert: Amorphous silica, generally associated with limestone. Often occur as irregular masses or lenses but can also occur finally disseminated through limestones. It may be very hard in unleached form. In leached form, it is white and "chalky" and is very absorptive. It has deleterious effect for aggregates to be used in Portland cement concrete due to reactivity with alkalies in Portland cement.

Clast: An individual constituent, grain or fragment of a sediment or rock, produced by the mechanical weathering of larger rock mass. Synonyms include particle and fragment.

Crushable Aggregate: Unprocessed gravel containing a minimum of 35% coarse aggregate larger than the No. 4 sieve (4.75 mm) as well as a minimum of 20% greater than the 26.5 mm sieve.

Deleterious lithology: A general term used to designate those rock types which are chemically or physically unsuited for use as construction or road-building aggregates. Such lithologies as chert, shale, siltstone and sandstone may deteriorate rapidly when exposed to traffic and other environmental conditions.

Devonian: A period of the Paleozoic Era thought to have covered the span of time between 408 and 360 million years ago, following the Silurian Period. Rocks formed in the Devonian Period are among the youngest Paleozoic rocks in Ontario.

Dolostone: A carbonate sedimentary rock consisting chiefly of the mineral dolomite and containing relatively little calcite (dolostone is also known as dolomite).

Drift: A general term for all unconsolidated rock debris transported from one place and deposited in another, distinguished from underlying bedrock. In North America, glacial activity has been the dominant mode of transport and deposition of drift. Synonyms include overburden and surficial deposit.

Drumlin: A low, smoothly rounded, elongated hill, mound, or ridge composed of glacial materials. These landforms were formed beneath an advancing ice sheet, and were shaped by its flow.

Eolian: Pertaining to the wind, especially with respect to landforms whose constituents were transported and deposited by wind activity. Sand dunes are an example of an eolian landform.

Fines: A general term used to describe the size fraction of an aggregate which passes (is finer than) the No. 200 mesh screen (0.075 mm). Also described informally as "dirt", these particles are in the silt and clay size range.

Glacial lobe: A tongue-like projection from the margin of the main mass of an ice cap or ice sheet. During the Pleistocene Epoch several lobes of the Laurentide continental ice sheet occupied the Great Lakes basins. These lobes advanced then melted back numerous times during the Pleistocene, producing the complex arrangement of glacial material and landforms found in Ontario.

Gneiss: A coarse-textured metamorphic rock with the minerals arranged in parallel streaks or bands. Gneiss is relatively rich in feldspar. Other common minerals found in this rock include quartz, mica, amphibole and garnet.

Gradation: The proportion of material of each particle size, or the frequency distribution of the various sizes which constitute a sediment. The strength, durability, permeability and stability of an aggregate depend to a great extent on its gradation. The size limits for different particles are as follows:

Boulder	more than 200 mm
Cobbles	75-200 mm
Coarse Gravel	26.5-75 mm
Fine Gravel	4.75-26.5 mm
Coarse Sand	2-4.75 mm
Medium Sand	0.425-2 mm
Fine Sand	0.075-0.425 mm
Silt, Clay	less than 0.075 mm

Granite: A coarse-grained, light-coloured rock that ordinarily has an even texture and is composed of quartz and feldspar with either mica, hornblende or both.

Granular Base and Subbase: Components of a pavement structure of a road, which are placed on the subgrade and are designed to provide strength, stability and drainage, as well as support for surfacing materials. Four types have been defined: Granular A consists of crushed and processed aggregate and has relatively stringent quality standards in comparison to Granular B which is usually pit-run or other unprocessed aggregate; Granular M is a shouldering and surface dressing material with quality requirements similar to Granular A; Select Subgrade Material has similar quality requirements to Granular B and it provides a stable platform for the overlying pavement structure. (For more specific information the reader is referred to Ontario Provincial Standard Specification OPSS 1010).

Heavy Duty Binder: Second layer from the top of hot mix asphalt pavements, used on heavily travelled (especially by trucks) expressways, such as Highway 401. Coarse and fine aggregates are to be produced from high quality bedrock quarries, except when gravel is permitted by special provisions.

Hot-laid (or Asphaltic) Paving Aggregate: Bituminous, cemented aggregates used in the construction of pavements either as surface or bearing course (HL 1, 3 and 4), or as binder course (HL 2, 4 and 8) used to bind the surface course to the underlying granular base.

Limestone: A carbonate sedimentary rock consisting chiefly of the mineral calcite. It may contain the mineral dolomite up to about 40%.

Lithology: The description of rocks on the basis of such characteristics as colour, structure, mineralogic composition and grain size. Generally, the description of the physical character of a rock.

Los Angeles Abrasion and Impact Test: This test measures the resistance to abrasion and the impact strength of aggregate. This gives an idea of the breakdown that can be expected to occur when an aggregate is stockpiled, transported and placed. Values less than about 35% indicate potentially satisfactory performance for most concrete and asphalt uses. Values of more than 45% indicate that the aggregate may be susceptible to excessive breakdown during handling and placing.

Magnesium Sulphate Soundness Test: This test is designed to simulate the action of freezing and thawing on aggregates. Those aggregates which are susceptible to freezing and thawing will usually break down and give high losses in this test. Values greater than about 12 to 15% indicate potential problems for concrete and asphalt coarse aggregate.

Medium Duty Binder: Second layer from the top of hot mix asphalt pavements used on heavily travelled, usually four lane highways and municipal arterial roads. It may be constructed with high quality quarried rock or high quality gravel with a high percentage of fractured faces or polymer modified asphalt cements.

Meltwater Channel: A drainage way, often terraced, produced by water flowing away from a melting glacier margin.

Ordovician: An early period of the Paleozoic Era thought to have covered the span of time between 505 and 438 million years ago.

Paleozoic Era: One of the major divisions of the geologic time scale thought to have covered the time period between 570 and 230 million years ago, the Paleozoic Era (or Ancient Life Era) is subdivided into six geologic periods, of which only four (Cambrian, Ordovician, Silurian and Devonian) can be recognized in southern Ontario.

Petrographic Examination: An aggregate quality test based on known field performance of various rock types. In Ontario the test result is a Petrographic Number (PN). The higher the PN, the lower the quality of the aggregate.

Pleistocene: An epoch of the recent geological past including the time from approximately 2 million years ago to 7000 years ago. Much of the Pleistocene was characterized by extensive glacial activity and is popularly referred to as the "Great Ice Age".

Polished Stone Value: This test measures the frictional properties of aggregates after 6 hours of abrasion and polishing with an emery abrasive. The higher the PSV, the higher the frictional properties of the aggregate. Values less than 45 indicate marginal frictional properties, while values greater than 55 indicate excellent frictional properties.

Possible Resource: Reserve estimates based largely on broad knowledge of the geological character of the deposit and for which there are few, if any, samples or measurements. The estimates are based on assumed continuity or repetition for which there are reasonable geological indications, but do not take into account many site-specific natural and environmental constraints that could render the resource unaccessible.

Precambrian: The earliest geological period extending from the consolidation of the earth's crust to the beginning of the Cambrian Period.

Sandstone: A clastic sedimentary rock consisting chiefly of sand-sized particles of quartz and minor feldspar, cemented together by calcareous minerals (calcite or dolomite) or by silica.

Shale: A fine-grained, sedimentary rock formed by the consolidation of clay, silt or mud and characterized by well-developed bedding planes, along which the rock breaks readily into thin layers. The term shale is also commonly used for fissile claystone, siltstone and mudstone.

Siltstone: A clastic sedimentary rock consisting chiefly of silt-sized particles, cemented together by calcareous minerals (calcite and dolomite) or by silica.

Silurian: An early period of the Paleozoic era thought to have covered the time between 438 and 408 million years ago. The Silurian follows the Ordovician Period and precedes the Devonian Period.

Soundness: The ability of the components of an aggregate to withstand the effects of various weathering processes and agents. Unsound lithologies are subject to disintegration caused by the expansion of absorbed solutions. This may seriously impair the performance of road-building and construction aggregates.

Till: Unsorted and unstratified rock debris, deposited directly by glaciers, and ranging in size from clay to large boulders.

Wisconsinan: Pertaining to the last glacial period of the Pleistocene Epoch in North America. The Wisconsinan began approximately 100 000 years ago and ended approximately 7000 years ago. The glacial deposits and landforms of Ontario are predominantly the result of glacial activity during the Wisconsinan Stage.

Appendix C – Geology of Sand and Gravel Deposits

The type, distribution and extent of sand and gravel deposits in Ontario are the result of extensive glacial and glacially influenced activity in Wisconsinan time during the Pleistocene Epoch, approximately 100 000 to 7000 years ago. The deposit types reflect the different depositional environments that existed during the melting and retreat of the continental ice masses, and can readily be differentiated on the basis of their morphology, structure and texture. The deposit types are described below.

GLACIOFLUVIAL DEPOSITS

These deposits can be divided into two broad categories: those that were formed in contact with (or in close proximity to) glacial ice, and those that were deposited by meltwaters carrying materials beyond the ice margin.

Ice-Contact Terraces (ICT): These are glaciofluvial features deposited between the glacial margin and a confining topographic high, such as the side of a valley. The structure of the deposits may be similar to that of outwash deposits, but in most cases the sorting and grading of the material is more variable and the bedding is discontinuous because of extensive slumping. The probability of locating large amounts of crushable aggregate is moderate, and extraction may be expensive because of the variability of the deposits both in terms of quality and grain size distribution.

Kames (K): Kames are defined as mounds of poorly sorted sand and gravel deposited by meltwater in depressions or fissures on the ice surface or at its margin. During glacial retreat, the melting of supporting ice causes collapse of the deposits, producing internal structures characterized by bedding discontinuities. The deposits consist mainly of irregularly bedded and crossbedded, poorly sorted sand and gravel. The present forms of the deposits include single mounds, linear ridges (crevasse fillings) or complex groups of landforms. The latter are occasionally described as "undifferentiated ice-contact stratified drift" (IC) when detailed subsurface information is unavailable. Since kames commonly contain large amounts of fine-grained material and are characterized by considerable variability, there is generally a low to moderate probability of discovering large amounts of good quality, crushable aggregate. Extractive problems encountered in these deposits are mainly the excessive variability of the aggregate and the rare presence of excess fines (silt- and clay-sized particles).

Eskers (E): Eskers are narrow, sinuous ridges of sand and gravel deposited by meltwaters flowing in tunnels within or at the base of glaciers, or in channels on the ice surface. Eskers vary greatly in size. Many, though not all eskers, consist of a central core of poorly sorted and stratified gravel characterized by a wide range in grain size. The core material is often draped on its flanks by better sorted and stratified sand and gravel. The deposits have a high probability of containing a large proportion of crushable aggregate, and since they are generally built above the surrounding ground surface, are convenient extraction sites. For these reasons esker deposits have been traditional aggregate sources throughout Ontario, and are significant components of the total resources of many areas.

Some planning constraints and opportunities are inherent in the nature of the deposits. Because of their linear nature, the deposits commonly extend across several property boundaries leading to unorganized extractive development at numerous small pits. On the other hand, because of their form, eskers can be easily and inexpensively extracted and are amenable to rehabilitation and sequential land use.

Undifferentiated Ice-Contact Stratified Drift (IC): This designation may include deposits from several ice-contact, depositional environments which usually form extensive, complex landforms. It is not feasible to identify individual areas of coarse-grained material within such deposits because of their lack of continuity and grain size variability. They are given a qualitative rating based on existing pit and other subsurface data.

Outwash (OW): Outwash deposits consist of sand and gravel laid down by meltwaters beyond the margin of the ice lobes. The deposits occur as sheets or as terraced valley fills (valley trains) and may be very large in extent and thickness. Well-developed outwash deposits have good horizontal bedding and are uniform in grain size distribution. Outwash deposited near the glacier's margin is much more variable in texture and structure. The probability of locating useful crushable aggregates in outwash deposits is moderate to high depending on how much information on size, distribution and thickness is available.

Subaqueous Fans (SF): Subaqueous fans are formed within or near the mouths of meltwater conduits when sediment-laden meltwaters are discharged into a standing body of water. The geometry of the resulting deposit is fan- or lobe-shaped. Several of these lobes may be joined together to form a larger, continuous sedimentary body. Internally, subaqueous fans consist of stratified sands and gravels which may exhibit wide variations in grain size distribution. As these features were deposited under glacial lake waters, silt and clay which settled out of these lakes may be associated in varying amounts with these deposits. The variability of the sediments and presence of fines are the main extractive problems associated with these deposits.

Alluvium (AL): Alluvium is a general term for clay, silt, sand, gravel, or similar unconsolidated material deposited during postglacial time by a stream as sorted or

semi-sorted sediment, on its bed or on its floodplain. The probability of locating large amounts of crushable aggregate in alluvial deposits is low, and they have generally low value because of the presence of excess silt- and clay-sized material. There are few large postglacial alluvium deposits in Ontario.

GLACIOLACUSTRINE DEPOSITS

Glaciolacustrine Beach Deposits (LB): These are relatively narrow, linear features formed by wave action at the shores of glacial lakes that existed at various times during the deglaciation of Ontario. Well developed lacustrine beaches are usually less than 6 m thick. The aggregate is well sorted and stratified and sand-sized material commonly predominates. The composition and size distribution of the deposit depends on the nature of the source material. The probability of obtaining crushable aggregate is high when the material is developed from coarse-grained materials such as a stony till, and low when developed from fine-grained materials. Beaches are relatively narrow, linear deposits, so that extractive operations are often numerous and extensive.

Glaciolacustrine Deltas (LD): These features were formed where streams or rivers of glacial meltwater flowed into lakes and deposited their suspended sediment. In Ontario such deposits tend to consist mainly of sand and abundant silt. However, in near-ice and ice-contact positions, coarse material may be present. Although deltaic deposits may be large, the probability of obtaining coarse material is generally low.

Glaciolacustrine Plains (LP): The nearly level surface marking the floor of an extinct glacial lake. The sediments which form the plain are predominantly fine to medium sand, silt and clay, and were deposited in relatively deep water. Lacustrine deposits are generally of low value as aggregate sources because of their fine grain size and lack of crushable material. In some aggregate-poor areas, lacustrine deposits may constitute valuable sources of fill and some granular subbase aggregate.

GLACIAL DEPOSITS

End Moraines (EM): These are belts of glacial drift deposited at, and parallel to, glacier margins. End moraines commonly consist of ice-contact stratified drift and in such instances are usually called kame moraines. Kame moraines commonly result from deposition between two glacial lobes (interlobate moraines). The probability of locating aggregates within such features is moderate to low. Exploration and development costs are high. Moraines may be very large and contain vast aggregate resources, but the location of the best areas within the moraine is usually poorly defined.

EOLIAN DEPOSITS

Windblown Deposits (WD): Windblown deposits are those formed by the transport and deposition of sand by winds. The form of the deposits ranges from extensive, thin layers to well-developed linear and crescentic ridges known as dunes. Most windblown deposits in Ontario are derived from, and deposited on, pre-existing lacustrine sand plain deposits. Windblown sediments almost always consist of fine to coarse sand and are usually well sorted. The probability of locating crushable aggregate in windblown deposits is very low.

Appendix D - Geology of Bedrock Deposits

The purpose of this appendix is to familiarize the reader with the general bedrock geology of southern Ontario (Figure D1) and, where known, the potential uses of the various bedrock formations. The reader is cautioned against using this information for more specific purposes. The stratigraphic chart (Figure D2) is intended only to illustrate the stratigraphic sequences in particular geographic areas and should not be used as a regional correlation table.

The following description is arranged in ascending stratigraphic order, on a group and formation basis. Precambrian rocks are not discussed. Additional stratigraphic information is included for some formations where necessary. The publications and maps of the Ontario Geological Survey (e.g. Johnson et al. 1992) and the Geological Survey of Canada should be referred to for more detailed information. The composition, thickness and uses of the formations are discussed. If a formation may be suitable for use as aggregate and aggregate suitability test data are available, the data have been included in the form of ranges. The following short forms have been used in presenting this data: PSV = Polished Stone Value, AAV = Aggregate Abrasion Value, $MgSO_4$ = Magnesium Sulphate Soundness Test (loss in percent), LA = Los Angeles Abrasion and Impact Test (loss in percent), Absn = Absorption (percent), BRD = Bulk Relative Density, PN (Asphalt & Concrete) = Petrographic Number for Asphalt and Concrete use. The ranges are intended as a guide only and care should be exercised in extrapolating the information to specific situations. Aggregate suitability test data has been provided by the Ontario Ministry of Transportation.

Covey Hill Formation (Cambrian)

STRATIGRAPHY: lower formation of the Potsdam Group. COMPOSITION: interbedded non-calcareous feldspathic conglomerate and sandstone. THICKNESS: 0 to 14 m. USES: has been quarried for aggregate in South Burgess Township, Leeds County.

Nepean Formation (Cambro-Ordovician)

STRATIGRAPHY: part of the Potsdam Group. COMPOSITION: thin- to massive-bedded quartz sandstone with some conglomerate interbeds and rare shaly partings. THICKNESS: 0 to 30 m. USES: suitable as dimension stone; quarried at Philipsville and Forfar for silica sand; alkali-silica reactive in Portland cement concrete. AGGREGATE SUITABILITY TESTING: PSV = 54-68, AAV = 4-15, $MgSO_4$ = 9-32, LA = 44-90, Absn = 1.6-2.6, BRD = 2.38-2.50, PN (Asphalt & Concrete) = 130-140.

March Formation (Lower Ordovician)

STRATIGRAPHY: lower formation of the Beekmantown Group. COMPOSITION: interbedded quartz sandstone, dolomitic quartz sandstone, sandy dolostone and dolostone. THICKNESS: 6 to 64 m. USES: quarried extensively for aggregate in area of subcrop and outcrop; alkali-silica reactive in Portland cement concrete; lower part of formation is an excellent source of skid-resistant aggregate. Suitable for use as facing stone and paving stone. AGGREGATE SUITABILITY TESTING: PSV = 55-60, AAV = 4-6, $MgSO_4$ = 1-17, LA = 15-38, Absn = 0.5-0.9, BRD = 2.61-2.65, PN (Asphalt & Concrete) = 110-150.

Oxford Formation (Lower Ordovician)

STRATIGRAPHY: upper formation of the Beekmantown Group. COMPOSITION: thin- to thick-bedded, microcrystalline to medium-crystalline, grey dolostone with thin shaly interbeds. THICKNESS: 61 to 102 m. USES: quarried in the Brockville and Smith Falls areas and south of Ottawa for use as aggregate. AGGREGATE SUITABILITY TESTING: PSV = 47-48, AAV = 7-8, $MgSO_4$ = 1-4, LA = 18-23, Absn = 0.7-0.9, BRD = 2.74-2.78, PN (Asphalt & Concrete) = 105-120.

Rockcliffe Formation (Middle Ordovician)

STRATIGRAPHY: divided into lower member and upper (St. Martin) member. COMPOSITION: interbedded quartz sandstone and shale; interbedded shaly bioclastic limestone and shale predominating in upper member to the east. THICKNESS: 0 to 125 m. USES: upper member has been quarried east of Ottawa for aggregate; lower member has been used as crushed stone; some high purity limestone beds in upper member may be suitable for use as fluxing stone and in lime production. AGGREGATE SUITABILITY TESTING: PSV = 58-63, AAV = 10-11, $MgSO_4$ = 12-40, LA = 25-28, Absn = 1.8-1.9, BRD = 2.55-2.62, PN (Asphalt & Concrete) = 122-440.

Shadow Lake Formation (Middle Ordovician)

STRATIGRAPHY: eastern Ontario - the basal unit of the Ottawa Group; central Ontario - overlain by the Simcoe Group. COMPOSITION: in eastern Ontario - silty and sandy dolostone with shale partings and minor interbeds of sandstone; in central Ontario - conglomerates, sandstones, and shales. THICKNESS: eastern Ontario - 2 to 3 m; central Ontario - 0 to 12 m. USES: potential source of decorative stone; very limited value as aggregate source.

Gull River Formation (Middle Ordovician)

STRATIGRAPHY: part of the Simcoe Group (central Ontario) and Ottawa Group (eastern Ontario). In eastern Ontario the formation is subdivided into upper and lower members; in central Ontario it is presently subdivided into upper, middle and lower members. COMPOSITION: in central and eastern Ontario the lower member consists of alternating units of limestone, dolomitic limestone and dolostone, the upper member consists of thin-bedded limestones with thin shale partings; west of Lake Simcoe the lower member is thin- to thick-bedded, interbedded, grey argillaceous limestone and buff to green dolostone whereas the upper and middle members are dense microcrystalline limestones with argillaceous dolostone interbeds. THICKNESS: 7.5 to 136 m. USES: quarried in the Lake Simcoe, Kingston, Ottawa and Cornwall areas for crushed stone. Rock from certain layers in eastern and central Ontario has proven to be alkali-reactive when used in Portland cement concrete (alkali-carbonate reaction). AGGREGATE SUITABILITY TESTING: PSV = 41-49, AAV = 8-12, $MgSO_4$ = 3-13, LA = 18-28, Absn = 0.3-0.9, BRD = 2.68-2.73, PN (Asphalt & Concrete) = 100-153.

Bobcaygeon Formation (Middle Ordovician)

STRATIGRAPHY: part of the Simcoe Group (central Ontario) and the Ottawa Group (eastern Ontario), subdivided into upper, middle and lower members; members in eastern and central Ontario are approximately equivalent. COMPOSITION: homogeneous, massive to thin-bedded fine-crystalline limestone with numerous shaly partings in the middle member. THICKNESS: 7 to 87 m. USES: quarried at Brechin, Marysville, and in the Ottawa area for crushed stone. Generally suitable for use as granular base course aggregate. Rock from certain layers has been found to be alkali-reactive when used in Portland cement concrete (alkali-silica reaction). AGGREGATE SUITABILITY TESTING: PSV = 47-51, AAV = 14-23, $MgSO_4$ = 1-40, LA = 18-32, Absn = 0.3-2.4, BRD = 2.5-2.69, PN (Asphalt & Concrete) = 100-320.

Verulam Formation (Middle Ordovician)

STRATIGRAPHY: part of Simcoe and Ottawa Groups. COMPOSITION: fossiliferous, pure to argillaceous limestone interbedded with calcareous shale. THICKNESS: 32 to 65 m. USES: quarried at Picton and Bath for use in cement manufacture. Quarried for aggregate in Ramara Township, Simcoe County and in the Belleville–Kingston area. May be unsuitable for use as aggregate in some areas because of its high shale content. AGGREGATE SUITABILITY TESTING: PSV = 43-44, AAV = 9-13, $MgSO_4$ = 4-45, LA = 22-29, Absn = 0.4-2.1, BRD = 2.59-2.70, PN (Asphalt & Concrete) = 120-255.

Lindsay Formation (Middle Upper Ordovician)

STRATIGRAPHY: part of Simcoe and Ottawa Groups; in eastern Ontario is divisible into an unnamed lower member and the Eastview Member; in central Ontario is divisible into the Collingwood Member (equivalent to portions of the Eastview Member) and a lower member. COMPOSITION: eastern Ontario - the lower member is interbedded, very fine- to coarse-crystalline limestone with undulating shale partings and interbeds of dark grey calcareous shale, whereas the Eastview Member is an interbedded dark grey to dark brown calcareous shale and very fine- to fine-crystalline, petroliferous limestone; central Ontario - Collingwood Member is a black, calcareous shale whereas the lower member is a very fine- to coarse-crystalline, thin-bedded limestone with very thin, undulating shale partings. THICKNESS: 25 to 67 m. USES: eastern Ontario - lower member is used extensively for aggregate production; central Ontario - quarried at Picton, Ogden Point and Bowmanville for cement. May be suitable or unsuitable for use as concrete and asphalt aggregate. AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 2-47, LA = 20-28, Absn = 0.4-1.3, BRD = 2.64-2.70, PN (Asphalt & Concrete) = 110-215.

Blue Mountain and Billings Formations (Upper Ordovician)

STRATIGRAPHY: central Ontario - Blue Mountain Formation includes the upper and middle members of the former Whitby Formation; eastern Ontario - Billings Formation is equivalent to part of the Blue Mountain Formation. COMPOSITION: Blue Mountain Formation - blue-grey, noncalcareous shales; Billings Formation - dark grey to black, noncalcareous to slightly calcareous, pyritiferous shale with dark grey limestone laminae and grey siltstone interbeds. THICKNESS: Blue Mountain Formation - 43 to 61 m; Billings Formation - 0 to 62 m. USES: Billings Formation may be a suitable source for structural clay products and expanded aggregate; Blue Mountain Formation may be suitable for structural clay products.

Georgian Bay and Carlsbad Formations (Upper Ordovician)

COMPOSITION: central Ontario - Georgian Bay Formation composed of interbedded limestone and shale; eastern Ontario - Carlsbad Formation composed of interbedded shale, siltstone and bioclastic limestone. THICKNESS: Georgian Bay Formation - 91 to 170 m. Carlsbad Formation - 0 to 186 m. USES: Georgian Bay Formation - used by several producers in Metropolitan Toronto area to produce brick and structural tile, as well as for making Portland cement; at Streetsville, expanded shale was used in the past to produce lightweight ag-

gregate. Carlsbad Formation - used as a source material for brick and tile manufacturing, has potential as a lightweight expanded aggregate.

Queenston Formation (Upper Ordovician)

COMPOSITION: red, thin- to thick-bedded, sandy to argillaceous shale with green mottling and banding. THICKNESS: 45 to 335 m. USES: There are several large quarries developed in the Queenston Formation in the Toronto–Hamilton region and one at Russell, near Ottawa. All extract shale for brick manufacturing. The Queenston Formation is the most important source material for brick manufacture in Ontario.

Whirlpool Formation (Lower Silurian)

STRATIGRAPHY: lower formation in the Cataract Group in the Niagara Peninsula and the Niagara Escarpment as far north as Duntroon. COMPOSITION: massive, medium- to coarse-grained, argillaceous white to light grey quartz sandstone with thin grey shale partings. THICKNESS: 0 - 8 m. USES: building stone, flagstone.

Manitoulin Formation (Lower Silurian)

STRATIGRAPHY: part of the Cataract Group, occurs north of Stoney Creek. COMPOSITION: thin-bedded, blue-grey to buff-brown dolomitic limestones and dolostones. THICKNESS: 0 to 25 m. USES: extracted for crushed stone in St. Vincent and Sarawak townships, Grey County, and for decorative stone on Manitoulin Island.

Cabot Head Formation (Lower Silurian)

STRATIGRAPHY: part of the Cataract Group, occurs in subsurface throughout southwestern Ontario and outcrops along the length of the Niagara Escarpment. COMPOSITION: green, grey and red shales. THICKNESS: 10 to 39 m. USES: potential source of coated lightweight aggregate and raw material for use in manufacture of brick and tile. Extraction limited by lack of suitable exposures.

Grimsby Formation (Lower Silurian)

STRATIGRAPHY: upper formation of the Cataract Group, is identified on the Niagara Peninsula as far north as Clappison's Corners. COMPOSITION: interbedded sandstone and shale, mostly re... THICKNESS: 0 to 15 m. USES: no present uses.

Thorold Formation (Middle Silurian)

STRATIGRAPHY: lower formation in the Clinton Group on the Niagara Peninsula. COMPOSITION: thick-bedded quartz sandstone. THICKNESS: 2 - 3 m. USES: no present uses.

Neagha Formation (Middle Silurian)

STRATIGRAPHY: part of the Clinton Group on the Niagara Peninsula. COMPOSITION: dark-grey to green shale with minor interbedded limestone. THICKNESS: 0 to 2 m. USES: no present uses.

Dyer Bay Formation (Middle Silurian)

STRATIGRAPHY: on Manitoulin Island and northernmost Bruce Peninsula. COMPOSITION: highly fossiliferous, impure dolostone. THICKNESS: 0 to 7.5 m. USES: no present uses.

Wingfield Formation (Middle Silurian)

STRATIGRAPHY: on Manitoulin Island and northernmost Bruce Peninsula. COMPOSITION: olive green to grey shale with dolostone interbeds. THICKNESS: 0 to 15 m. USES: no present uses.

St. Edmund Formation (Middle Silurian)

STRATIGRAPHY: occurs on Manitoulin Island and northernmost Bruce Peninsula, upper portion previously termed the Mindemoya Formation. COMPOSITION: pale grey to buff-brown, micro- to medium-crystalline, thin- to medium-bedded dolostone. THICKNESS: 0 to 25 m. USES: quarried for fill and crushed stone on Manitoulin Island. AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 1-2, LA = 19-21, Absn = 0.6-0.7, BRD = 2.78-2.79, PN (Asphalt & Concrete) = 105.

Fossil Hill and Reynales Formations (Middle Silurian)

STRATIGRAPHY: Fossil Hill Formation occurs in the northern part of the Niagara Escarpment and is approximately equivalent in part to the Reynales Formation which occurs on the Niagara Peninsula and the Escarpment as far north as the Forks of the Credit. COMPOSITION: Fossil Hill Formation - fine- to coarse-crystalline dolostone with high silica content; Reynales Formation - thin- to thick-bedded shaly dolostone and dolomitic limestone. THICKNESS: Fossil Hill Formation 6 to 26 m; Reynales Formation 0 to 3 m. USES: both formations quarried for aggregate with overlying Amabel and Lockport Formations. AGGREGATE SUITABILITY TESTING: (Fossil Hill Formation on Manitoulin Island) $MgSO_4$ = 41, LA = 29, Absn = 4.1, BRD = 2.45, PN (Asphalt & Concrete) = 370.

Irondequoit Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group on the Niagara Peninsula south of Waterdown. COMPOSITION:

massive, coarse-crystalline crinoidal limestone. THICKNESS: 0 to 2 m. USES: not utilized extensively.

Rochester Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group along the Niagara Peninsula. COMPOSITION: black to dark grey calcareous shale with numerous limestone lenses. THICKNESS: 5 to 24 m. USES: not utilized extensively. AGGREGATE SUITABILITY TESTING: PSV = 69, AAV = 17, $MgSO_4$ = 95, LA = 19, Asbn = 2.2, BRD = 2.67, PN (Asphalt & Concrete) = 400.

Decew Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group south of Waterdown along the Niagara Peninsula. COMPOSITION: sandy to shaly dolomitic limestone and dolostone. THICKNESS: 0 to 5 m. USES: too shaley for high quality uses, but is quarried along with Lockport Formation in places. AGGREGATE SUITABILITY TESTING: PSV = 67, AAV = 15, $MgSO_4$ = 55, LA = 21, Absn = 2.2, BRD = 2.66, PN (Asphalt & Concrete) = 255.

Lockport and Amabel Formations (Middle Silurian)

STRATIGRAPHY: Lockport Formation occurs from Waterdown to Niagara Falls, subdivided into 3 formal members: Gasport, Goat Island and Eramosa Members, and an informal member (the "Vinemount shale beds"); the approximately equivalent Amabel Formation, found from Waterdown to Cockburn Island, has been subdivided into Lions Head, Wiarton/Colpoy Bay and Eramosa Members. On the Bruce Peninsula and in the subsurface of southwestern Ontario the Eramosa Member is considered to be part of the overlying Guelph Formation. COMPOSITION: Lockport Formation is thin- to massive-bedded, fine- to medium-crystalline dolostone; Amabel Formation is thin- to massive-bedded, fine- to medium-crystalline dolostone with reef facies developed near Georgetown and on the Bruce Peninsula. The Eramosa Member is thin bedded and bituminous. THICKNESS: (Lockport/Amabel) 3 to 40 m. USES: both formations have been used to produce lime, crushed stone, concrete aggregate and building stone throughout their area of occurrence, and are a resource of provincial significance. AGGREGATE SUITABILITY TESTING: PSV = 36-49, AAV = 10-17, $MgSO_4$ = 2-6, LA = 25-32, Absn = 0.4-1.54, BRD = 2.61-2.81, PN (Asphalt & Concrete) = 100-105.

Guelph Formation (Middle Silurian)

STRATIGRAPHY: exposed south and west of the Niagara Escarpment from the Niagara River to the tip of the Bruce Peninsula, mostly present in the subsurface of southwestern Ontario. COMPOSITION: fine- to medium-crystalline, medium- to thick-bedded, porous dolostone, characterized in places by extensive vuggy, porous reefal facies of high chemical purity. THICKNESS: 4 to 100 m. USES: some areas appear soft and unsuitable for use in the production of load-bearing aggregate. This unit requires additional testing to fully establish its aggregate suitability. Main use is for dolomitic lime for cement manufacture. Quarried near Hamilton and Guelph.

Salina Formation (Upper Silurian)

STRATIGRAPHY: present in the subsurface of southwestern Ontario; only rarely exposed at surface. COMPOSITION: grey and maroon shale, brown dolostone and, in places, salt, anhydrite and gypsum; consists predominantly of evaporitic-rich material with up to eight units identifiable. THICKNESS: 113 to 330 m. USES: gypsum mines at Hagersville, Caledonia and Drumbo. Salt is mined at Goderich and Windsor and is produced from brine wells at Amherstburg, Windsor and Sarnia.

Bertie and Bass Islands Formations (Upper Silurian)

STRATIGRAPHY: Bertie Formation found in southern Niagara Peninsula; Bass Islands Formation, the Michigan Basin equivalent of the Bertie Formation, rarely outcrops in Ontario but is present in the subsurface in southwestern Ontario; Bertie Formation represented by Oatka, Falkirk, Scajaquanda, Williamsville and Akron Members. COMPOSITION: medium- to massive-bedded, micro-crystalline, brown dolostone with shaly partings. THICKNESS: 14 to 28 m. USES: quarried for crushed stone on the Niagara Peninsula; shaly intervals are unsuitable for use as high specification aggregate because of low freeze-thaw durability. Has also been extracted for lime. AGGREGATE SUITABILITY TESTING: PSV = 46-49, AAV = 8-11, $MgSO_4$ = 4-19, LA = 14-23, Absn = 0.8-2.8, BRD = 2.61-2.78, PN (Asphalt & Concrete) = 102-120.

Oriskany Formation (Lower Devonian)

STRATIGRAPHY: basal Devonian clastic unit, found in Niagara Peninsula. COMPOSITION: thick- to massive-bedded, coarse-grained, grey-yellow sandstone. THICKNESS: 0 to 5 m. USES: has been quarried for silica sand, building stone and armour stone. May be acceptable for use as rip rap, and well-cemented varieties may be acceptable for some asphaltic products. AGGREGATE SUITABILITY TESTING: (of a well-cemented variety of the formation) PSV = 64, AAV = 6, $MgSO_4$ = 2, LA = 29, Absn = 1.2-1.3, BRD = 2.55, PN (Asphalt & Concrete) = 107.

Bois Blanc Formation (Lower Devonian)

STRATIGRAPHY: Springvale Sandstone Member forms the lower portion of formation. COMPOSITION: a cherty limestone with shale partings and minor interbedded dolostones; Springvale Sandstone Member is a medium- to coarse-grained, green glauconitic sand-

stone with interbeds of limestone, dolostone and brown chert. THICKNESS: 3 to 40 m. USES: quarried at Hagersville, Cayuga and Port Colborne for crushed stone. Material generally unsuitable for concrete aggregate because of high chert content. AGGREGATE SUITABILITY TESTING: PSV = 48-53, AAV = 3-7, $MgSO_4$ = 3-18, LA = 15-22, Absn = 1.3-2.8, BRD = 2.50-2.70, PN (Asphalt & Concrete) = 102-290.

Onondaga Formation (Lower - Middle Devonian)

STRATIGRAPHY: correlated to part of the Detroit River Group; occurs on the Niagara Peninsula from Simcoe to Niagara Falls; contains the Edgecliff, Clarence and Moorehouse Members. COMPOSITION: medium-bedded, fine- to coarse-grained, dark grey-brown or purplish-brown, variably cherty limestone. THICKNESS: 8 to 25 m. USES: quarried for crushed stone on the Niagara Peninsula at Welland and Port Colborne. High chert content makes much of the material unsuitable for use as concrete aggregate and asphaltic concrete. Has been used as a raw material in cement manufacture. AGGREGATE SUITABILITY TESTING: (Clarence and Edgecliff Members) $MgSO_4$ = 1-6, LA = 16.8-22.4, Absn = 0.5-1.1, PN (Asphalt & Concrete) = 190-276.

Amherstburg Formation (Lower - Middle Devonian)

STRATIGRAPHY: part of Detroit River Group; correlated to Onondaga Formation in Niagara Peninsula; contains Sylvania Sandstone Member and Formosa Reef Limestone. COMPOSITION: bituminous, bioclastic, stromatoporoid-rich limestone with grey chert nodules; Formosa Reef Limestone - high purity (calcium-rich) limestone; Sylvania Sandstone Member - quartz sandstone. THICKNESS: 0 to 60 m; Formosa Reef Limestone - up to 26 m. USES: cement manufacture, agricultural lime, aggregate. AGGREGATE SUITABILITY TESTING: PSV = 57, AAV = 19, $MgSO_4$ = 9-35, LA = 26-52, Absn = 1.1-6.4, BRD = 2.35-2.62, PN (Asphalt & Concrete) = 105-300.

Lucas Formation (Middle Devonian)

STRATIGRAPHY: part of the Detroit River Group in southwestern Ontario; includes the Anderdon Member which, in the Woodstock–Beachville area, may constitute the bulk of the formation. COMPOSITION: light brown or grey-brown dolostone with bituminus laminations and minor chert; Anderdon Member consists of very high purity (calcium-rich) limestone and locally, sandy limestone. THICKNESS: 40 to 75 m. USES: most important source of high-purity limestone in Ontario. Used as calcium lime for metallurgical flux and for the manufacture of chemicals. Rock of lower purity is used for cement manufacture, agricultural lime and aggregate. Anderdon Member is quarried at Amherstburg for crushed stone. AGGREGATE SUITABILITY TESTING: PSV = 46-47, AAV = 15-16, $MgSO_4$ = 2-60, LA = 27-47, Absn = 1.1-6.5, BRD = 2.35-2.40, PN (Asphalt & Concrete) = 110-160.

Dundee Formation (Middle Devonian)

STRATIGRAPHY: few natural outcrops, largely in the subsurface of southwestern Ontario. COMPOSITION: fine- to medium-crystalline, brownish-grey, medium- to thick-bedded, dolomitic limestone with shaly partings, sandy layers, and chert in some areas. THICKNESS: 15 to 45 m. USES: quarried near Port Dover and on Pelee Island for crushed stone. Used at St. Marys as a raw material for Portland cement. AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 1-28, LA = 22-46, Absn = 0.6-6.8, PN (Asphalt & Concrete) = 125-320.

Marcellus Formation (Middle Devonian)

STRATIGRAPHY: subsurface unit, mostly found below Lake Erie and extending into the eastern USA, pinches out in the Port Stanley area. COMPOSITION: black, bituminous shales. THICKNESS: 0 to 12 m. USES: no present uses.

Bell Formation (Middle Devonian)

STRATIGRAPHY: lowest formation of the Hamilton Group, no outcrop in Ontario. COMPOSITION: soft, blue and grey calcareous shale. THICKNESS: 0 to 14.5 m. USES: no present uses.

Rockport Quarry Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group; no outcrop in Ontario. COMPOSITION: grey-brown, very fine-grained limestone with occasional shale layers. THICKNESS: 0 to 6 m. USES: no present uses.

Arkona Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. COMPOSITION: blue-grey, plastic, clay shale with occasional thin and laterally discontinuous limestone lenses. THICKNESS: 5 to 37 m. USES: has been extracted at Thedford and near Arkona for the production of drainage tile.

Hungry Hollow Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. COMPOSITION: grey crinoidal limestone and soft, fossiliferous calcareous shale. THICKNESS: 0 to 2 m. USES: suitable for some crushed stone and fill with selective quarrying.

Widder Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. COMPOSITION: mainly soft, grey, fossiliferous calcareous

shale interbedded with blue-grey, fine-grained fossiliferous limestone. THICKNESS: 0 to 21 m. USES: no present uses.

Ipperwash Formation (Middle Devonian)

STRATIGRAPHY: upper formation of the Hamilton Group; very limited distribution. COMPOSITION: medium- to coarse grained, grey-brown, bioclastic limestone. THICKNESS: 2 to 14 m. USES: no present uses.

Kettle Point Formation (Upper Devonian)

STRATIGRAPHY: occurs in a northwest-trending band between Sarnia and Erieau; small part overlain by Port Lambton Group rocks in extreme northwest. COMPOSITION: black, highly fissile, organic-rich shale with minor interbeds of grey-green silty shale. THICKNESS: 0 to 75 m. USES: possible source of material for use as sintered lightweight aggregate or fill.

Bedford Formation (Upper Devonian or Mississippian)

STRATIGRAPHY: lower formation of the Port Lambton Group. COMPOSITION: soft, grey shale. THICKNESS: 0 to 30 m. USES: no present uses.

Berea Formation (Upper Devonian or Mississippian)

STRATIGRAPHY: middle formation of the Port Lambton Group; not known to occur at surface in Ontario. COMPOSITION: grey, fine- to medium-grained sandstone, often dolomitic and interbedded with grey shale and siltstone. THICKNESS: 0 to 60 m. USES: no present uses.

Sunbury Formation (Upper Devonian or Mississippian)

STRATIGRAPHY: upper formation of the Port Lambton Group; not known to occur at surface in Ontario. COMPOSITION: black shale. THICKNESS: 0 to 20 m. USES: no present uses.

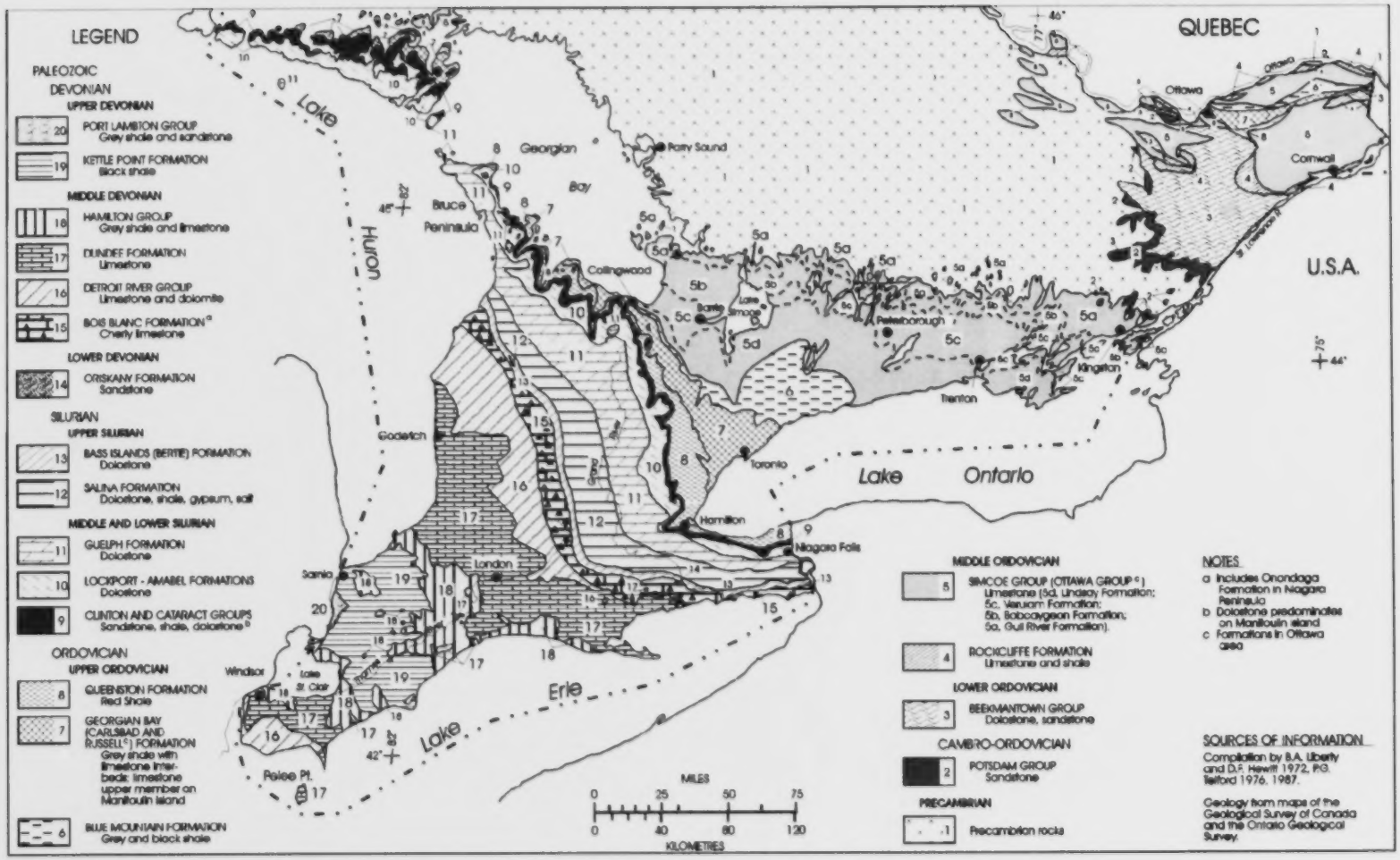

Figure D1. Bedrock geology of southern Ontario.

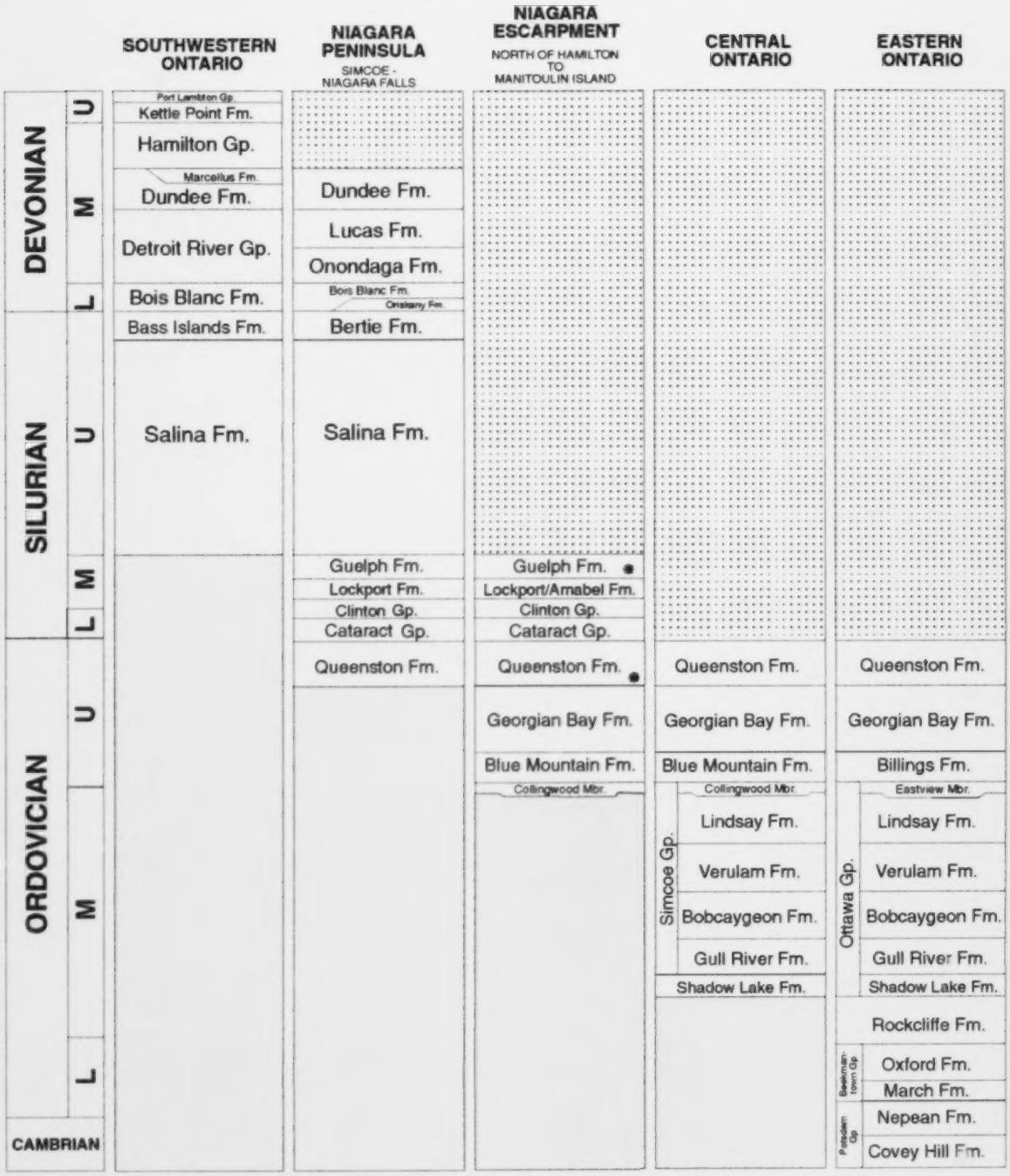

Figure D2. Exposed Paleozoic stratigraphic sequences in southern Ontario (*adapted from*: Bezys, R.K. and Johnson, M.D. 1988. The geology of the Paleozoic formations utilized by the limestone industry of Ontario; The Can. Mining and Metallurgical Bulletin,v.81, no. 912, p.49-58.)

Appendix E – Aggregate Quality Test Specifications

Six types of aggregate quality tests are often performed by the Ontario Ministry of Transportation on sampled material. A description and the specification limits for each test are included in this appendix. Although a specific sample meets or does not meet the specification limits for a certain product, it may or may not be acceptable for that use based on field performance. Additional quality tests other than the six tests listed in this appendix can be used to determine the suitability of an aggregate. The tests are performed by the Ontario Ministry of Transportation.

Absorption Capacity: Related to the porosity of the rock types of which an aggregate is composed. Porous rocks are subject to disintegration when absorbed liquids freeze and thaw, thus decreasing the strength of the aggregate. This test is conducted in conjunction with the determination of the sample's relative density.

Los Angeles Abrasion and Impact Test: This test measures the resistance to abrasion and the impact strength of aggregate. This gives an idea of the breakdown that can be expected to occur when an aggregate is stockpiled, transported and placed. Values less than about 35% indicate potentially satisfactory performance for most concrete and asphalt uses. Values of more than 45% indicate that the aggregate may be susceptible to excessive breakdown during handling and placing.

Magnesium Sulphate Soundness Test: This test is designed to simulate the action of freezing and thawing on aggregate. Those aggregates which are susceptible will usually break down and give high losses in this test. Values greater than about 12 to 15% indicate potential problems for concrete and asphalt coarse aggregate.

Micro-Deval Abrasion Test: The Micro-Deval Abrasion test is an accurate measure of the amount of hard, durable materials in sand-sized particles. This abrasion test is quick, cheap and more precise than the fine aggregate Magnesium Sulphate Soundness test that suffers from a wide multilaboratory variation. The maximum loss for HL 1/HL 3 is 20%, for HL 2 and HL 4/HL 8 it is 25% and for structural and pavement concrete it is 20%. It is anticipated that this test will replace the fine aggregate Magnesium Sulphate Soundness test.

Mortar Bar Accelerated Expansion Test: This is a rapid test for detecting alkali-silica reactive aggregates. It involves the crushing of the aggregate and the creation of standard mortar bars. For coarse and fine aggregates, suggested expansion limits of 0.10 to 0.15% are indicated for innocuous aggregates, greater than 0.10% but less than 0.20% indicates that it is unknown whether a potentially deleterious reaction will occur, and greater than 0.20% indicates that the aggregate is probably reactive and should not be used for Portland cement concrete. If the expansion limit exceeds 0.10% for coarse and fine aggregates, it is recommended that supplementary information be developed to confirm that the expansion is actually because of alkali-reactivity. If confirmed deleteriously reactive, the material should not be used for Portland cement concrete unless corrective measures are undertaken such as the use of low- or reduced-alkali cement.

Petrographic Examination: Individual aggregate particles in a sample are divided into categories good, fair, poor and deleterious, based on their rock type (petrography) and knowledge of past field performance. A petrographic number (PN) is calculated. The higher the PN, the lower the quality of the aggregate.

Table E1. Selected quality requirements for major aggregate products.

TYPE OF TEST						
	COARSE AGGREGATE				FINE AGGREGATE	
TYPE OF MATERIAL	**Petrographic Number Maximum**	**Magnesium Sulphate Soundness Maximum% Loss**	**Absorption Maximum%**	**Los Angeles Abrasion Maximum% Loss**	**Micro-Deval Abrasion Maximum % Loss**	**Magnesium Sulphate Soundness Maximum % Loss**
Granular A	200	-	-	60		-
Granular B Type 1	250*	-	-	-		-
Granular B Type 2	250	-	-	60		-
Granular M	200	-	-	60		-
Granular S	200	-	-	-		-
Select Subgrade Material	250	-	-	-		-
Open Graded Drainage Layer (1)	160	15	2.0	35		-
Hot Mix-HL 1, DFC, OFC	See OPSS 1149 and Special Provision No. 313S10					
Surface Treatment Class 1	135	12	1.75	35		-
Surface Treatment Class 2	160	15	-	35		-
Surface Treatment Class 3	160	12	2.0	35		-
Surface Treatment Class 4	-	-	-	-		20
Surface Treatment Class 5	135	12	1.75	35		-
Hot Mix - HL 1	100	5	1.0	15	20	16
Hot Mix - HL 2	-	-	-	-	25	20
Hot Mix - HL 3	135	12	1.75	35	20	16
Hot Mix - HL 4	160	12	2.0	35	20	20
Hot Mix - HL 8	160	15	2.0	35	25	20
Structural Concrete, Sidewalk, Curb, Gutter and Base	140	12	2.0	50	20	16
Pavement Concrete	125	12	2.0	35	20	16

* requirement waived if the material has more than 80% passing the 4.75 mm sieve
(1) Hot mix and concrete petrographic number applies
(Ontario Provincial Standard Specifications OPSS 304, OPSS 1002, OPSS 1003, OPSS 1010 and OPSS 1149)

Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
		LENGTH			
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
		AREA			
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
		VOLUME			
1 cm^3	0.061 023	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m^3
		CAPACITY			
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
		MASS			
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 90**	t
		CONCENTRATION			
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.